DISINFECTION AND DISINFECTANTS

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CHAPTER I.

INTRODUCTORY.

DISINFECTION is primarily a tool, which is placed in the hands of those following a special calling—the care and treatment of the sick—and in those of the world at large. It is, moreover, a complicated tool, its application necessitating not only practice but also intelligence, that is to say, a knowledge of the causes and methods of dissemination of infectious diseases; and also familiarity with the method and sphere of action of the several kinds of disinfection.

Although it is true that, for practical use, instructions for the performance of disinfection, which give full details and are intended to preclude all risk of error, have been issued by more or less competent authorities, experience nevertheless shows that, even in the simple kinds of disinfection errors are committed which may prejudice the entire results. The natural consequence is that the causes of the non-success of the method—which in itself may be a very suitable one—are concealed. Expert supervision or inspection is, however, indispensable in practice.

As a collection of fundamental facts, disinfection is also a not unimportant branch of hygienic science; and an exhaustive course of study is necessary in order to become an expert in the subject. Like the science of hygiene, that of disinfection only partially possesses

methods of its own, both chemical, physical and bacteriological methods of investigation having to render assistance; but the adaptation or development of these methods in association with the special biological methods is specific in character. The description of the methods of investigation is, however, reserved to the scientific publications dealing with the subject, the present work being concerned solely with the results obtained.

Disinfection is the prevention of infection. Infectious diseases are set up by micro-organisms belonging to the lowest orders of the vegetable (protophytes, bacteria, budding fungi and mould fungi) and animal (protozoa) kingdoms. These organisms act partly by the production of poisonous substances, either inside or outside the body; partly by destroying individual portions of the body, and also by inundating the whole body and producing functional disturbance of same. Except in the case of certain toxic micro-organisms—such as those causing allontiasis—which do not in themselves give rise to symptoms of disease, the infectious diseases always have as their starting-point the infected human or animal organism; but the path traversed by the pathogenic germ from its original habitat to a new organism differs, not only in different diseases, but also in one and the same complaint. Such diseases as those of the genital organs, wound infection, leprosy. plague, anthrax and rabies are communicated by th direct contact between diseased and healthy bodie and also occasionally through the hands, body-liner brushes, sponges, instruments (catheters), etc. Dr atmospheric dust forms the means of transmitting th germs of measles, scarlet fever, smallpox, chickenpo and tuberculosis. The drops of fluid produced in cough

ing, sneezing, singing, talking and laughing, frequently contain the germs of tuberculosis, epidemic spotted fever, influenza, phthisis, diphtheria, whooping-cough and glanders; and on account of their high power of remaining in suspension, are carried by currents of air into the respiratory tracts of men or animals in the vicinity. The disease germs, such as those of typhoid, dysentery and cholera occurring in the fæces or urine, may also be disseminated into the environment through the impact of a stream of liquid against a solid substratum or the surface of a liquid—for example, during urination or defecation, the emptying of utensils, the splashing of bath water, etc. The soil frequently harbours the resting forms of tetanus, anthrax and malignant œdema; whilst water may carry the germs of cholera, typhoid fever and dysentery. The former (soil) occasionally finds its way into skin wounds, and the latter (water) is taken as a beverage; and in this way the germs find an opportunity of causing disease. Foodstuffs in general are also excellent nutrient media for all kinds of pathogenic germs, which develop luxuriantly therein when once they have gained access. This explains why the germs of tuberculosis, diphtheria, influenza, cholera, typhoid and dysentery, and the micro-organisms producing ptomaine poisons and allontiasis are frequently discovered in foods. Finally, insects are transmitters of disease. Flies carry, on their legs and internally, the germs of infectious diseases which are localized in the intestines, which germs they take up along with particles of excrementitious matters and deposit them on foodstuffs. Mosquitoes, gnats, bugs, fleas and lice suck the blood of persons suffering from sleeping-sickness, malaria, yellow fever, relapsing fever, plague and spotted fever,

and reinoculate the germs into healthy organisms. It must also be borne in mind that the transmission of disease frequently proceeds in a very complicated manner. A germ excreted in fæcal matter may be carried for some distance on a boot, then transferred farther by insects, and still farther from hand to hand —sometimes through a very long chain. Moreover, it must not be forgotten that, in many diseases, the dissemination of the germs does not cease with the cessation of the clinical symptoms, but may continue for weeks and even months; that there are light forms of disease, in which the general well-being of the patient is only slightly affected, if at all, although he may give off pathogenic germs that exhibit undiminished virulence (healthy germ carriers).

When it is also remembered that the disease germs differ considerably in their capacity for existence outside the body, it will be evident that special methods require to be adopted for disinfection in each disease, such methods being based on the special circumstances, if success is to be commensurate with the trouble entailed. The elaboration of these methods forms the task of disinfection as a specialized subject, whilst the present work is restricted to general disinfection, that is to say, the preparation of disinfectants, their mode of action and scope of efficiency.

Attempts at disinfection are nearly as old as the human race itself. We read of the effects of Boreas in the plague-stricken quarters of Babylon; and Homer wrote about wood smoke and sulphur fumes. The cult of the bath in the later periods of antiquity was a semi-conscious attempt at disinfection; and in the Middle Ages, the fear of devastating plagues gave rise to the strangest notions regarding the prevention of infection. The re-

ports on the burning of witches, penning goats in pest-houses, and so forth, testify the confusion occasioned in the human mind by the superstition of the age. It was not until about a hundred years ago that any accurate perception of the possibility of preventing infection began to dawn among the enlightened. At the turn of the eighteenth century, Peter Frank, Plenciz, Count Rumford, and above all the celebrated chemist Lavoisier held generally accurate views on the nature of infection and made what were in part really practical proposals for preventing same. Lavoisier, for instance, instigated a regulation, in virtue of which all persons received into prisons and hospitals were bathed and made to don clothing provided by the State, their own garments being disinfected in hot-air cupboards. Half a century ago, Lister inaugurated the antiseptic treatment of wounds; and shortly afterwards Pasteur came on the scene with his highly important researches on the causes of fermentation, etc. It was not, however, until the epoch-making discovery of Robert Koch in connection with the causes of disease, and his method of pure culture of the disease germs, that the subject of disinfection was opened up to scientific treatment; and it is only from that date—in the early eighties of the last century—that the science of disinfection came into existence. During the last three decades this science has attained extensive development.

CHAPTER II.

PHYSICAL DISINFECTION.

THE term "disinfection" means freeing articles from adherent disease germs. This result can be achieved either by removing these germs in an unaltered condition, or else by destroying their pathological activity (i.e. their vitality) on the spot.

In the former event the disease germs are got rid by mechanical agencies. Thus germs are eliminated from drinking water by means of compact filters. In the case of walls, the topmost layer (dust, etc.), accompanied by the germs adhering thereto, is removed by rubbing it with bread; and finally, one may regard as mechanical disinfection the practice of covering over with a coat of paint (and thus rendering harmless) the germs adhering to the surface of solid objects. All such precautions belong undoubtedly to the sphere of disinfection, though in the narrower sense the term is restricted to the second category, in which the disease germs are destroyed.

The annihilation of all the micro-organisms in and upon an object is the final aim of sterilization, an operation originally based on a different course of ideas. Only a small proportion of the germs found on the earth's surface are pathogenic, the majority being putrefactive, that is to say having the property of decomposing dead organic matter. In order to preserve from decompo-

sition readily decomposable foodstuffs and other organic objects, attempts were made to free the same, and everything coming in contact therewith, from adherent micro-organisms, that is to say, to sterilize them. Since disease germs are included in this category, and form only a small body in comparison with the putrefactive organisms, the term sterilization covers a wider field than "disinfection" and always includes the latter, though the converse does not apply. Nevertheless, in practice, the two expressions are frequently used as synonymous—and for the most part correctly so.

It should be taken as an axiom that the processes of disinfection must always be regarded from two points of view, the biological and the physical, the former treating of the action of the disinfecting medium on the micro-organisms, and the latter dealing with its behaviour towards the articles to which those organisms adhere. One may also speak of two stages of disinfection: the first consisting in the penetration of the disinfectant on the outside or inside an object as far as the hiding-places of the germs, whilst the second stage is concerned with the destruction of said germs. The physical side of the operation may in many cases be so insignificant as to be negligible; but it is always desirable to ascertain this definitely, in order that nothing may be omitted.

It is therefore the task of the science of disinfection to examine the individual disinfecting agents on both sides; and it may be taken for granted that specific properties in one direction or the other will occasionally be discovered. On the biological side the micro-organisms constitute the point of attack. In general their power of resistance to disinfecting agents varies

considerably, so that in this respect a graduated scale could be drawn up. The graduations, however, will not exactly coincide for the different disinfectants, and furthermore, the individual species do not behave identically throughout the whole of their races and stocks; on the contrary they sometimes exhibit remarkable divergencies. In testing disinfectants it has therefore become the practice to determine a limit value up to which the agent is effectual, and by comparing this limit value with that of a thoroughly investigated known agent (for example steam at 212° F.) obtain a basis for judging its efficacy.

Disinfecting agents are very numerous; in fact, everything capable of injuring the vitality of micro-organisms is a disinfectant, provided, of course, that vitality is understood to mean propagative capacity. Agents which are able to restrict propagation merely during the time they continue to act, but do not injure the propagative capacity so that after their influence is removed reproduction goes on once more without hindrance, are mostly grouped under the name of preservatives. In the nature of things, moreover, a substance may be a disinfectant when more highly concentrated, and a preservative when in a more dilute condition.

In order to systematize this wide subject, a distinction is drawn between physical and chemical disinfectants. Any closer definition of the two is superfluous, the explanation being self-evident.

I. Heat.

The most powerful factor of disinfection known is heat.

(*a*) *Dry Heat.*

The existence of the disease germ is adapted to the temperature of its animal habitat, namely about 85° F. on the surface of the human body and that of warm-blooded animals, and about 96° F. within the body itself, the figures being somewhat higher in the case of birds, and 18° to 26° lower in cold-blooded animals—that is to say, the vital processes of the germ go on most actively at these temperatures. Now, whereas th higher animals are very sensitive to cold, those low in the scale do not freeze so readily, though even th lowest animals, the protozoa, will not always surviv freezing temperature unconditionally. Plants, on th other hand, have greater powers of resisting cold; f though the higher plants also suffer from the effects of frost, the lowest forms, the monocellular organism appear to be totally unaffected by even extreme de grees of cold. Even such delicate forms as the choler bacillus will remain alive in ice for months, and are n killed by the temperature of liquid air (−191° C.).

Micro-organisms have a minimum, maximum, an optimum temperature of development, the values o which vary considerably in different species. In som species of disease germs the minimum temperature lie just below the temperature of the body. These are th organisms which have become so habituated to para sitic existence that they are no longer able to surviv outside their host (obligate parasites), for example, th tubercle bacillus. Other species, such as the bacilli o cholera, typhoid and dysentery, are facultatively o semi-parasitic, i.e. can also reproduce themselves out side the body, and are therefore not dependent fo their existence on a very narrow range of temperature

the minimum being in such cases about 60° to 68° F. like that of the other semi-parasites. At the minimum temperature, reproduction is only very slight and barely detectable.

The maximum temperature plays a different part with regard to bacteria. When the temperature of an otherwise suitable nutrient medium is raised above the optimum, the reproductive tendency of the bacteria quickly retrogresses. There ensues a warm zone in which reproduction proceeds very sparsely, and this is followed by the maximum temperature, at which growth ceases altogether. In the case of most pathogenic germs this temperature is between 106° and 122° F., and they cannot stand it for more than a comparatively short time without injury. At the end of a few hours their vitality is so exhausted that they are unable to recover The more this maximum temperature is exceeded, the more rapidly do the bacteria perish. At 140° F. pathogenic germs generally die within an hour, and at 158 F. they succumb in a few minutes. Even the very few non-pathogenic bacteria able to stand higher temperatures than the disease germs are quickly destroyed at and above 158° F.

Hence nothing would be easier than to sterilize objects by the aid of heat, were it not that a number of bacteria are endowed with a peculiar property, discovered by Robert Koch at an early period of the bacteriological era, namely that these bacteria, under certain well-defined conditions—and especially when the nutrient medium or the temperature has become unsuitable—are able to produce resting forms or spores. These bodies are highly refractive globules which make their appearance in the interior of the bacterial cell, and survive when the remainder of the

organism at length undergoes decomposition. They will also remain unchanged for years when the conditions of existence are unfavourable: cold, scarcity of water or of food; and offer strong resistance to all forms of injury, including any kind of disinfection. In themselves they do not possess any reproductive faculty; but, when brought into a favourable environment, they will germinate again into the true bacterial form, the reproductive powers of which are unimpaired. In contrast to the spore form, the true bacterial form is known as the vegetative form.

The fundamental difference between spores and vegetative forms in respect of the fatal influence of heat was also identified by Robert Koch and his colleagues.

According to their description of the case, the spores are not affected in the least by temperatures exceeding 212° F., but will germinate again in normal fashion on being introduced into a nutrient medium. In fact the latent vitality of the spore is not destroyed until a temperature is attained at which the entire organic substance begins to char—or turn brown from superficial carbonization, as in the case of cotton—namely above 280° F. An explanation for this was subsequently afforded by Rubner, namely that white of egg, which, when dissolved, coagulates at 158° F. and is then no longer soluble, may be heated in the dry state to 248° F. and over without its solubility in water being impaired. As is shown by their high power of refracting light, bacterial spores consist of a highly concentrated protein; and their behaviour toward heat proves them to be nearly anhydrous in the ripe condition. On the other hand, as will be seen later on, they also behave toward moist heat in a manner analogous to dried white of egg, namely are readily destroyed.

The condition of affairs is therefore as follows: vegetative forms are easily killed by temperatures of 158° to 212° F., resting forms only at temperatures above 280° F. This latter temperature, however, is so high that very few articles in general use can be exposed to it without injury. It would rapidly evaporate all liquids, and even water of crystallization or hygroscopically combined moisture, thus producing extreme desiccation of the articles in which they are contained; and all organic matter, vegetable or animal fibres, would be charred, etc.

Hence the only articles which can be subjected to a temperature high enough to destroy the spores as well are those which are already dry and capable of withstanding heat. Sterilization by heat is extensively employed in practice, even the heating of metallic instruments, needles, scalpels, etc., in a flame constituting a kind of heat sterilization. Since the temperature of any flame is far higher than that needed to destroy spores, the germs with which the flame comes in contact are annihilated at once. In so far as the article is heated above the said requisite temperature, reliable sterilization is attained, and since the heat supply from a flame is exceedingly large, only a short time is needed in any case to sterilize even the interior of large hollow articles.

It will also be clearly evident that when articles are burned, as is universally prescribed in the regulations for the disinfection of mattress straw, rags and other worthless objects, the disease germs also will be destroyed.

In addition to this somewhat rough and ready method, dry heat is also used in specially constructed forms of apparatus, such as are chiefly used in bacterio-

logical laboratories. These appliances for dry sterilization consist of jacketed boxes, the interior of which is intended for the reception of glass dishes, tubes, porcelain utensils and heavy metallic instruments. The air in the jacket spaces is heated by means of powerful Bunsen burners or other source of heat; and in this

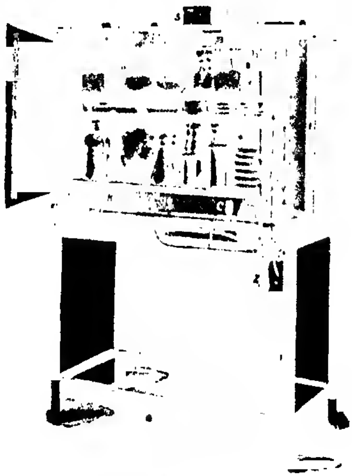

FIG. 1.—Dry Sterilizer

ABCE, Perforated gaspipes. Z, Gas cock. H, Articles to be disinfected. S, Flue for the hot gases issuing from the jacket space.

way the walls of the box are raised to a high temperature (Fig. 1). Whereas, under the practical condition hitherto discussed, the physical side of the application of heat plays a merely subordinate part, the manner in which the heat reaches to and penetrates into the articles to be disinfected in these apparatus is a matter of some importance. In dry sterilization the whole of

the inner walls of the apparatus form the source of heat. They are usually made of dark-coloured metal, in order to accelerate the heating of the disinfecting chamber, since dark surfaces transmit a somewhat large proportion of their heat by radiation. In this manner the surfaces facing the walls are very quickly heated, the articles being then heated through by conduction, both from the walls to the surface of the articles and between and through the articles themselves. The collaboration of heat conduction, which is a relatively slow method of transmission, would unduly prolong the time required for disinfection were it not that the internal dimensions of the apparatus are so chosen that, even with low conductivity, the internal space is certain to become heated above the desired limit of temperature within twenty to thirty minutes.

Latterly attention has again been directed to the question of the possibility of obtaining reliable and protective disinfection by the use of hot air at a temperature below the boiling point of water. The first to carry on experiments in this direction was Schumburg, who found that military clothing and equipment—especially leather-trimmed riding breeches, knapsacks, etc.—could be reliably disinfected without injury in a hot-air chamber at about 212° F. and with a relative humidity of about 55 per cent. For disinfecting books Ballner proposed to employ a temperature of 203° F., a relative humidity of 40 to 60 per cent and an exposure of four to six hours; but Mosebach and Findel obtained successful results with a still lower temperature, viz. 165°-175° F. The apparatus required for such disinfective treatment is very simple, and may consist of a sheet-iron vessel carefully heated from the outside, though it is better to use a box of the kind employed

for dry sterilizing, the jacket space being, however, filled with water, because this alters in temperature less quickly than air. In order to avoid the necessity for continuous observation the heating is regulated by an automatic device (see p. 37). The desired degree of humidity is obtained by placing a larger or smaller water tray in the bottom of the apparatus.

It is clear, *ab initio*, that spores can never be killed by this means, though it has been reliably proved that all vegetative forms are destroyed. As will be evident from the foregoing, the treatment relates solely to articles of use. Except in rare instances, the only sporogenic bacteria that are pathologic in man are anthrax and tetanus bacilli. Of the other disease germs, two in particular present great difficulty in the matter of disinfection: the tubercle bacillus and staphylococcus. The first named, a slender rod and the cause of tuberculosis, has a compact epidermis, which contains a fatty or waxy substance. This affords the bacillus extensive protection against desiccation and various chemical agents, though the power of resisting heat is not much greater than in other bacteria, the wax-like mass apparently melting between 60° and 70° C. The staphylococcus, which is the cause of pus in wounds, blood poisoning and puerperal fever, is a small globular bacterium, the individuals forming aggregations similar to bunches of grapes. There are numerous races and stocks of staphylococcus—including non-pathogenic kinds—differing considerably in their power of withstanding external influences, some of them being almost equal to many kinds of spores in this respect. Though, for scientific investigations, it is necessary to ascertain the resisting properties of each stock of staphylococcus, it is quite correct to assume, in general, that the

staphylococci are among the most highly resistant of disease germs attacking the human subject.

Both these bacterial species can be effectually destroyed by exposure to a temperature of 75° to 80° C. for several minutes; and this treatment will also kill all other vegetative forms. The question now arises as to the articles that can best be treated by this means.

The sporogenic germs: tetanus and anthrax, transmit infection through skin wounds. Consequently, such articles of clothing—shoes, riding breeches, gloves, fur caps, etc.—which come, or might come, into direct contact with the skin, cannot be reliably disinfected at 75° to 80° C., since this treatment does not destroy the spores. The danger threatened by these spores should not be held in such light esteem as is usually the case; and experience shows that furs are often infested with the spores of anthrax, and that tetanus spores are not infrequently detected in boots. For outer garments, on the other hand, this method of disinfection is more suitable; and it would be most advantageous in the case of books, were it not for a practical obstacle.

It is true that books also may come in contact with the skin, when taken into the hands; but never in such a way as to cause a wound by pressure or rubbing. Consequently, the risk of infection by the sporogenic germs in question is reduced to a minimum. On the other hand, books are feared as transmitters of diseases which spread through the air, and especially by means of atmospheric dust: scarlet fever, measles, smallpox, tuberculosis, diphtheria, whooping-cough and influenza. At present the germs of the three first-named complaints are still unidentified, but it is certain that, like the other disease germs, they do not produce resting forms of the spore type. Consequently, all these germs are

inevitably killed by a temperature of 75° to 80° C., provided they are actually exposed to such temperature for a certain time, not less than half an hour.

The last proviso is not superfluous, the physical conditions playing an important part in this connexion. Books are infected not merely on the outside, but inside as well; and in order to make sure that they are really disinfected, one must be able to rely on the necessary temperature having prevailed in all parts.

The manner in which the books get warmed right through is as follows: The internal spaces of the hot-air chamber (box) having been filled with the books, the jacket space is heated, and the heat passes from the inner walls to the books themselves, by radiation and conduction. The darker the colour of the surfaces, the more important the part played by radiation; but this merely transmits the heat to the surfaces nearest the source of heat. Conduction takes place through the intervening stratum of air to the nearest surface, and since air is a bad conductor of heat, the amount conducted depends entirely on the thickness of that stratum. The closer the books are to the wall, the more quickly will that side which faces the wall become heated. In these circumstances the surfaces farthest away from the walls remain cool at first.

Hence a technical advantage is secured by taking measures to ensure that all the surfaces are bathed with hot air, and thus heated uniformly; since in such case the heat penetrates into the interior of the book from both sides at once, and the book is warmed through twice as quickly. This object can be achieved by placing the books, singly or in small bundles, in a cupboard through which an adequate supply of properly heated air is passed.

It may be objected that the rate at which the warming through is effected makes no practical difference; but it does. Thus, if a heating chamber measuring 20 inches each way inside be packed full of books, it will take quite forty-eight hours to warm the lot right through, the transmission of heat through the mass of books proceeding at an exceedingly slow rate because effected solely by conduction. This method of transmission, already slow in itself, is rendered still more so by the material of which the books are composed, namely vegetable (and partly also animal) fibres, which transmit heat only about $\frac{1}{1000}$ as fast as iron or $\frac{1}{8000}$ as fast as silver. The air is a still poorer conductor than the fibres, and the more porous the texture of the books, the greater the relative difficulty in warming them through.

According to Findel, the presence of 30 per cent of humidity (produced by trays of water) in the disinfecting chamber, is more favourable to the operation than a lower degree of humidity. The reason for this has not yet been elucidated, and it must be left an open question whether the more favourable results are not due to some other cause.

Although the theoretical and practical basis for the prophylactic disinfection of books, leather goods, etc., has now been established in the manner described, this method of disinfection has not yet succeeded in gaining any adherents in practice. The reason for this is the comparatively long time required for disinfection, amounting to twenty-four to forty-eight hours for even small apparatus, and the considerable quantity of heating power needed in consequence. Added to this are the not inconsiderable technical difficulties in the supply of heat to the larger apparatus, such as would be needed

for large libraries and other institutions in which books, leather, and furs are used.

(b) *Moist Heat (Steam).*

1. Ordinary Steam.

Disinfecting by steam heat is a very convenient method of procedure. At the ordinary atmospheric pressure, the temperature of steam that has not been influenced in any way is 100° C.; and all that is necessary to heat an article of moderate size to that temperature is to place it in the steam zone of a pan which can be easily covered up in the usual way and in which water is maintained in a constant state of ebullition. This is the principle of the old Koch steamer (Fig. 2), the only special feature of which, apart from its high shape, is that it is covered with felt to prevent loss of heat.

The use of steam, however, possesses certain special and very important advantages. In his original work, Robert Koch already showed that bacterial spores behaved very differently in presence of steam—or, as he termed it, "moist heat"—than towards dry heat. Most spores, and among them those of tetanus and anthrax, are killed by steam at 100° C. in a few minutes, either by the material of the spores swelling up in the saturated steam, or merely by the fact that, under these conditions, the rapid drying which takes place in dry heat is retarded. This case also is analogous to the behaviour of dried albumin, which is coagulated by direct contact with steam, and is thus rendered insoluble. It is true that many spores—and chief among them the potato bacilli found in the soil—cannot be killed by a brief exposure to steam, but require treatment for several hours. These are quite exceptionally

resistant spores, which require to be dealt with another way.

It may be interpolated here that the so-called fractional process of sterilization is required for sterilizing nutrient media for bacteriological purposes—a process which, of course, may also be employed in sterilizing foodstuffs. The vessels containing the nutrient media or food are placed for a quarter to half an hour in the steamer, this treatment killing the vegetative forms, but leaving the resistant spores intact. The vessels are then left for twenty-four hours at room temperature, to give the spores an opportunity of germinating into vegetative forms. This done, the vessels are put into the steamer a second time, which kills the new vegetative growth. As a rule, this will complete the sterilization, though generally the steaming is repeated once more after another interval of twenty-four hours, to provide against the contingency of any resting forms having survived the previous treatment.

FIG. 2.—Koch's steamer.

The biological advantages of steam disinfection—namely the powerful destructive action on the spores—is accompanied by others of a physical character, consisting mainly in the comparatively short time required for the disinfection. Directly the water reaches boiling point, steam is given off in large quantities, and warms all the articles in the steam zone through very quickly, provided the same are permeable to steam.

According to Rubner, a distinction can be drawn

between impervious, porous and semi-porous bodies. Now, steam can only penetrate where open pores (i.e. interstitial air spaces) exist. The class of porous substances includes all textile fabrics: silk, wool, cotton, linen, jute, hemp (but not leather), or other goods made of fibres, strips, or hair. These are in general easily penetrable by steam; but they may resist penetration when their pores are not open. This is the case when the air spaces are restricted by the goods being pressed into large bales, or when these spaces are obstructed by drops of water. The practical consequence is that one cannot expect large bales of goods to be disinfected right through to the centre by steam. As a matter of fact, even after prolonged steaming, the temperature in the middle of the bales is only raised very slightly, and therefore no germs there are killed. Hence, only articles that are dry (in the ordinary sense) should be subjected to steam disinfection, and the deposition of steam on the surface of the articles must be prevented. This prevention is secured by warming up the contents of the steaming chamber beforehand by dry heat, since, at the most, only small quantities of steam can condense on warm surfaces.

The manner in which the steam penetrates into the air spaces is also important. In the first place it should be mentioned that steam at 100° C. is only about one-half the weight of air at 20° C. (68° F.) and only two-thirds that of air at 100° C. Consequently, when steam is introduced into a closed chamber, it rises to the top and collects above the air in all cases. If the cover were provided with an exhaust pipe, the steam would escape through it, as being the gas in nearest proximity. In order to expel the air from the chamber, the exhaust pipe must be situated in the

bottom of the latter, in which event the air will be driven out by the overlying steam. It is therefore advisable to admit the steam into the top of the sterilizer, as it does not, in that case, mix with the air so much as if it had to flow through the latter, this mixing with the air having, as will be seen later, an adverse influence on the efficiency of the process. The provision of an outlet for the air, in the bottom of the apparatus, is equally essential, since otherwise only a small quantity of steam can be admitted into the apparatus, any further amount either escaping through leaks, or else damming back the supply by the pressure set up. In such event the gaseous contents of the apparatus will be chiefly composed of air.

The steam penetrates into the pores of the articles in the same way as it enters the total space, namely from above, a fact that can be easily demonstrated. In this case also the driving force is, of course, the difference in the specific gravity of steam and air. On the other hand, it is again essential that the air should be able to escape downwards; for if this be impossible, owing to the pores being choked or constricted, no steam can enter them.

The penetration of steam into the pores is facilitated by the circumstance that most materials are hygroscopic (i.e. absorb moisture). Deposition of water also invariably occurs in the pores, because at first the interstitial spaces are not as hot as the steam. This water, however, is at once re-evaporated by the oncoming steam. The condensation—even though slight—in the pores, always caused a reduction in pressure, which favours the penetration of steam—a circumstance which may help to account for the rapidity with which porous articles are permeated by steam.

In any case, steam disinfection is a quick process, the air being expelled from the apparatus and pores in a few minutes when the apparatus is properly constructed. The rate at which this is effected depends on the quantity of steam admitted per unit of space in unit time. A large apparatus naturally requires more steam. In the case of large articles with complicated internal spaces—articles of clothing and bedding—the expulsion of the air is retarded to some extent; but it may be taken for granted that unless the steam has thoroughly penetrated within half an hour, it will not do so at all owing to one or other of the causes mentioned above.

Such cases do occur in practice, the bundles of goods under treatment being too large, or damp, or excessive surface condensation having occurred in the apparatus from some cause or other. It is therefore easy to understand the desire for possessing some means of ascertaining whether the interior of the articles under treatment has been effectually disinfected. Wherever the steam comes into action a temperature of 100° C. must necessarily prevail, whereas the parts untouched by the steam are only slightly warmed (owing to the slow conduction). If one can be certain that the steam temperature has actually been attained in the portions most difficult of access, it will be equally certain that the bacteria have been destroyed. In order to check the temperature, various proposals have been advanced; but only two have found practical application. The first of these consists of a small cylindrical vessel, partially filled (to about ½) with a substance of known melting point—phenandrene, with a melting point of 98° C. being used in the case of saturated steam, and pyrocatechin (m.p. 105° C.) for high-pressure steam.

The mass naturally solidifies in the bottom of the cylindrical vessel which, for the purpose of checking the temperature, is placed vertically (but upside down) in the centre of the material under treatment. If, at the close of the disinfecting process, the mass is found to have run down to the bottom of the cylinder, its melting point has evidently been exceeded in the centre of the material, and therefore the latter has been hot enough for the purpose in view.

Unfortunately, this simple method is attended with the drawback that the repeated meltings alter the melting point of the mass to such an extent that it soon becomes unreliable as a thermometer. For this reason, the alternative and more reliable method is now frequently used. This consists in embedding a maximum thermometer in the middle of the articles under treatment, the temperature attained being either read off direct, or, better still, by the aid of a signalling device, consisting of an electric bell thermometer, the contact of which is set to operate at 100° C. (or any other desired temperature). The wires are led externally to a bell and are connected with a battery. When the steam penetrates to the thermometer, the mercury column rises and, on reaching 100° C., touches the contact, the circuit being thus completed and the bell rung. All that is then necessary, therefore, is to wait a sufficient time for the destruction of the spores.

This method of disinfecting with ordinary steam at 100° C., based on the principles enunciated above, has attained considerable practical importance, owing to its rapidity, effectiveness and harmlessness for most articles of use, bandages, bedding, clothing, coverlets, etc., being chiefly sterilized in this manner. On the other hand it cannot be used for leather, furs, delicate fabrics,

fine colours, ladies' hats, sized and other susceptible materials. Apparatus of all sizes can be met with in use, two patterns being worthy of special mention as the most popular and typical. One of them, a small apparatus, is suitable for sterilizing bandages, operating overalls, etc., and consists of a, generally cylindrical, jacketed box, fitted with a cover.

The materials to be disinfected are piled up loosely

FIG. 3.—Apparatus for Steam Disinfection.

A, Boiler. B, Disinfecting chamber. C, Rack for articles to be disinfected. D, Condenser.

in the internal space, which is provided underneath with an exhaust pipe. The lower part of the jacket space is filled with water, and when this is heated, the resulting steam ascends through the jacket space, heating the inner walls and thereby the whole of the chamber (warming up stage).

This steam then enters the chamber through perforations in the top of the inner wall, and drives the air downward.

The second pattern (Figs. 3, 4, and 5) is for disinfection on the large scale in hospitals and disinfecting stations. The disinfection chamber is generally large enough to accommodate a whole bed. It is built in a partition wall and is provided with two openings into two different rooms, one for the dirty articles and the other for their reception after disinfection. The articles are taken out of the chamber into this second room by a different attendant from the one who puts

FIG. 4.—Apparatus for Steam Disinfection (closed).

them into the chamber. This arrangement is intended to prevent re-infection of the disinfected articles. In addition to the exhaust pipe, the bottom of the chamber is provided with radiators, which can be heated to 100° C. by steam, for the purpose of warming up the chamber and its contents, and also for drying the damp articles when air is admitted to the chamber after the operation is completed. The steam, which can be supplied from any boiler, quite as well as from a special generator, is used for dry heating in the radiators, and is

admitted into the top of the chamber for disinfecting. When properly worked, these apparatus act quite satisfactorily.

The properties of water vapour are due to its temper-

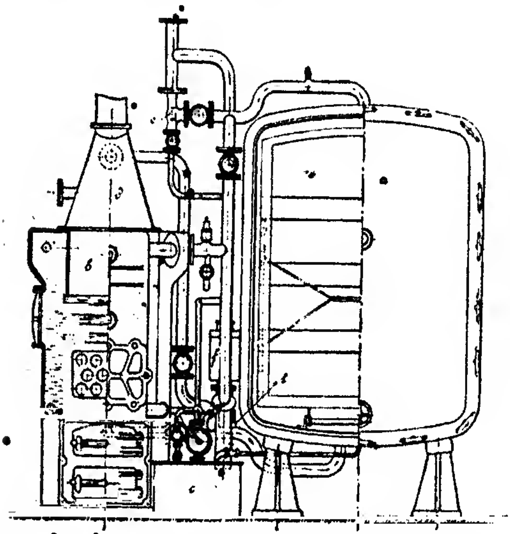

FIG. 5.—Lautenschläger Apparatus for Steam Disinfection, with Steam Generator.

a, Disinfection chamber. *b*, Steam generator. *c*, Feed tank. *d*, Air heater. *e*, Steam injector for evacuating the chamber. *f*, Mercury safety gauge. *t*, Thermometer.

ature and humidity. This explains both its advantages and drawbacks, not only in the case of ordinary water vapour, given off at the normal atmospheric pressure, but also in the case of all kinds of artificially generated steam. A distinction must be drawn between pure steam

and such as is admixed with air, the first named again being divided into ordinary, high-pressure, superheated and attenuated (sub-normal pressure) steam. The decisive advantage of the steaming process is undoubtedly its power of destroying spores; and in this respect the different kinds of steam must be compared.

2. Impure Steam.

The temperature of the steam is not reduced to any great extent by its contamination with air, the latter (itself already warmed) mixing so intimately with the steam that it soon attains the same temperature. On the other hand, the presence of this air lowers the humidity of the mixture, since the steam only brings with it sufficient moisture to saturate the space it occupies itself. This assumption also corresponds with Rubner's observation that when steam contains 8·4 per cent of air the time required to kill the spores of anthrax is prolonged from one to three minutes, whereas with 20 per cent of air the spores are not destroyed at the end of three hours. This proves that whilst the presence of up to 10 per cent of air in the steam considerably weakens its disinfectant action, it still remains effective; but that, on the other hand, a higher percentage of air renders the steam inoperative. One still occasionally comes across apparatus in which the steam is liberated over an extensive surface at the bottom, and in ascending—frequently retarded by the piled up articles under treatment—is obliged to become mixed with a large proportion of air. In such cases a careful examination would always reveal the inefficiency of the process. In the case of modern types of apparatus, in which the steam is admitted from above, this defect is precluded.

3. Superheated Steam.

When steam is allowed to flow through or over a heated pipe, it becomes superheated, that is to say, its temperature is raised, its proportion of moisture, however, remaining unchanged. However, since a larger number of particles of water are needed to produce saturation at the higher temperature, this heating desaturates the steam and thus deprives it of an effective weapon of attack on the life of bacterial spores. In this condition it can merely act as a dry gas; and every experiment shows that superheated steam has only just the same disinfecting power as air at the same temperature, i.e. it does not begin to destroy spores until above 140° C. (284° F.). Hence, for practical purposes, superheated steam is out of the running, since it offers no advantages over the more easily prepared hot air.

4. Steam under Pressure.

The conditions are different with the steam produced when water is boiled under a pressure exceeding that of the atmosphere. Whereas at mean atmospheric pressure (760 mm. mercury gauge), water boils at 100° C., the boiling point increases with the pressure, so that when the latter reaches two atmospheres (29½ lb. per square inch), the water does not begin to boil below 121° C., and with a pressure of three atmospheres, at 135° C. An increased (or diminished) pressure can only be set up in a hermetically closed vessel, since otherwise the normal atmospheric pressure would be automatically restored. Such increased or diminished pressure can be obtained in such a closed vessel by forcing in (or drawing out) air into (or from) the space above the water by means of an air pump. The most convenient

way, however, of increasing the pressure is by allowing the disengaged steam to accumulate, all that is necessary being to heat the boiler and see that it is properly closed. As soon as the boiling point of water (at first 100° C.) is reached, steam is generated in large quantities, and when this steam is prevented from escaping it is bound to become compressed in proportion as the amount of water converted into steam by the heat of the boiler increases. This compression of the steam increases the steam pressure, which in turn raises the boiling point of the water and therefore the temperature of the steam itself. The question whether the water becomes progressively heated above the constantly increasing boiling point will depend on the way the boiler is fired. If a very hot fire is maintained the pressure might rise to such a degree as to burst the boiler were it not that all such boilers are obliged to be fitted with a safety valve, and must also be tested for their strength.

The two properties, saturation and temperature, also come in question for the disinfecting action of steam under pressure. This steam, being saturated, is therefore not inferior to ordinary steam in this respect; and, being hotter than the last named, must therefore be superior to it on the whole. The hotter the steam, the greater its power of killing spores. For example, the spores of the most highly resistant hay or potato bacilli, which are not destroyed by steam at 100° C. in an hour, are killed by steam at a pressure of two atmospheres (temperature 121° C.) in about twenty minutes, and in a still shorter time when the steam pressure is higher.

A large number of modern apparatus for disinfecting and sterilizing are arranged on this principle, though mostly for working at only 105° to 110° C., which

correspond to pressures of 3 to 7½ lb. per square inch. Some apparatus, however, the so-called autoclaves (Fig. 6), are constructed to work at steam pressures up to three atmospheres. They are generally arranged on the lines of the steamers already described (p. 25), that is to say, with a jacket space for generating the steam; but they must meet the conditions exacted of boilers constructed to work at the corresponding pressure, namely pass official tests and be fitted with safety valves. It must be clearly remembered that the same remarks apply to all these steamers as to the ordinary forms, namely that provision must be made for the escape of air from the interior, if the action is to be effective, that is to say, the vessel must not be hermetically sealed until the steam begins to issue from the bottom, thus denoting that all the air has been expelled.

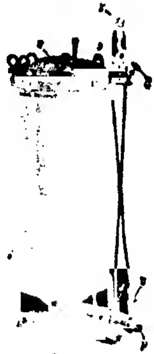

FIG. 6.—Autoclave. A, Casing. B, Cover. D, Wing nuts for closing the vessel hermetically. C, Set screw for adjusting to the desired maximum pressure with the aid of a special pointer on the gauge dial. E, Pressure gauge. F, Gas pipe. H, Safety valve. G & J, Pressure gauge tube.

5. Low-temperature Steam.

Until recently, this class of steam was of merely theoretical interest; but, in combination with chemical disinfectants, it has latterly attained considerable importance. (For this combination see p. 89.)

There is only one way to obtain saturated low-temperature steam, namely by lowering the pressure over the water to be evaporated. As increased pressure raises the boiling point of water, so reduced pressure

lowers it. On high mountains, where the atmospheric pressure is below the normal, water no longer requires heating to 100° C. to cause it to boil, ebullition taking place at a lower temperature. If one half the air in a hermetically closed boiler be evacuated by pumping, saturated steam at 90° C. can be generated by the application of heat. In such case, however, the liberated steam will replace the evacuated air, and soon bring the pressure up to the normal again, and the boiling-point and steam temperature will rise to 100° C., and even higher in a hermetically closed vessel. Consequently, to continue working at diminished pressure for any length of time, it is necessary to keep the air pump running continuously and drawing off the steam as generated. The method of firing the boiler must also be harmonized with the working of the air pump, their action being mutually opposed. The heat generates steam and thus tends to equalize the pressure, whilst the pump endeavours to reduce the pressure still lower; and consequently these two opposing forces must be brought into equilibrium.

In order to obtain some idea of the relation between the boiling point of water and the natural or artificial increase or decrease in pressure, the following extract from the tables compiled in this connection is now given (see opposite).

With regard to the efficiency of steam under reduced pressure as a disinfectant, Rubner's investigations have shown that saturated steam at a temperature a few degrees below 100° C. has almost the same effect on spores as steam at 100° C. Between 90 and 95° C., this action diminishes appreciably and at about 80° C. the steam entirely loses its power of destroying spores. Steam under these conditions has the same effect on vege-

Boiling point. °C.	Pressure. mm.	Boiling point. °C	Pressure. mm.
0	4·6	95	634·0
10	9·2	100	760·0
20	17·4	105	906·4
30	31·6	110	1075·4
40	55·0	115	1269·4
50	92·2	120	1491·0
60	149·2	125	1744·0
70	233·8	130	2030·0
80	355·5	135	2286·0
85	433·8	140	2718·0
90	526·0	145	3125·0
		150	3581·0

ative forms as hot air at corresponding temperatures—out this point does not come into consideration at present. Consequently no effective disinfection can be produced by ow-temperature steam if the temperature is reduced to any considerable extent.

Varied as are the applications of steam disinfection n the case of porous articles, it is unsuitable in many cases. In the first place, it must be applied in some form of apparatus, so that, in general, articles of very arge size cannot be treated; and secondly, its high temperature—which is essential to success—is not always free from the risk of injuring the articles treated.

Leather, for instance, in particular, will not stand high temperatures. Some kinds of leather shrink up even at 140° F. (65° C.) to about one-third their original size and become stiffly elastic, for instance the tanned skins of wild animals, usually employed for making gloves. Other kinds of leather are also damaged by slightly higher temperatures, so that boots, gloves and other leather goods come out of the steam disinfecting appa-

ratus in a completely shrunken condition and unfit for further use. The same remarks, as will be readily evident, also apply to furs.

Fine fabrics are also destroyed by steaming; and many dyes that will not properly stand washing are dissolved, even fast-washing colours being extracted. Sized articles lose their stiffness; documents are warped and the ink caused to "run"; books suffer damage in several respects, the leather bindings shrinking, the size being extracted, the leaves warped and the letter-press faded, and for the most part they fall to pieces after the operation of steaming. Blood stains on linen and clothing are burnt in so effectually as to be no longer eradicable. It should also be mentioned that flowers and leaves are completely destroyed by steaming, as it has occasionally been proposed to disinfect wreaths or the like by this means.

It is of no little importance that the effects of steam at boiling-point, and also at slightly higher and lower temperatures, should be known, since this knowledge will enable considerable losses to be avoided in practice.

(c) *Hot Liquids.*

After what has been stated with regard to steam, the disinfecting action of these liquids will easily be comprehended.

1. Water.

To begin with the means most frequently employed in daily life, namely hot water, its efficiency may be briefly described by the statement that it has exactly the same disinfecting power as steam, the same preliminary conditions—same temperature and complete humidity—being present. This identity of action is

not restricted to water boiling at ordinary atmospheric pressure (212° F.), but extends also to all conditions whether induced by natural or artificial means. When water is boiled under high pressure, as in the Papin digester, its disinfecting properties are intensified in precisely the same way as those of the resulting steam; and when boiled under diminished pressure, at high altitudes, the effect of the hot water is reduced like that of steam.

Under normal conditions, i.e. a barometric pressure of 760 mm., the vegetative forms of bacteria are killed almost instantly, and most spores perish in a few minutes. In any event the chief sporogenic organisms that are pathogenic to the human subject (the bacilli of anthrax and tetanus) can be counted upon with certainty to be killed in two to three minutes, as a general thing, or at latest in fifteen minutes. Consequently the prescription of boiling for half an hour, in practical work, will certainly be ample to ensure complete disinfection.

Boiling water is chiefly used in practical disinfection, for sterilizing instruments and ordinary body linen, for two reasons: in the first place, the apparatus required is simple, any ordinary tub being sufficient, since the water expels all the air out of the pores from below, and not, like steam, entering the articles from above; secondly, because the boiling water wets the articles right through, dissolving and washing out all dirt and other contaminating substances.

The vessels used for sterilizing surgical instruments are merely boiling pans adapted to the special requirements of the instruments under treatment; that is to say, they are of elongated shape (Fig. 7), like fish kettles, in order to accommodate long instruments, and

usually narrow, so as to economize space, water, and therefore heating material. A small quantity of carbonate of soda is usually added to the water, but merely for the purpose of preventing metal parts from rusting.

Fig. 7.—Apparatus for Sterilizing Instruments.

Boiling water is also employed for sterilizing foodstuffs. For this purpose, however, the water does not exert any direct germicide action, but serves merely as the source of heat, the actual disinfection being effected by the liquids contained in the foodstuffs themselves, which liquids are heated to the temperature of the boiling water. The method is a very convenient one, since it guarantees the attainment of a well-defined and invariable temperature, viz. 212° F. The best known example of this method is that of Soxhlet for sterilizing milk, the full bottles of milk being placed in boiling water, where the milk is quickly raised to nearly 212° F. and freed almost entirely from germs.[1]

Other foodstuffs can be rendered free from germs in the same way. The method is very useful for protecting the contents of vessels from subsequent contamination and for preventing the germination of residual spores.

These remarks will show clearly how far the use of hot water, below 212° F. is advisable for disinfection.

[1] The only spores remaining alive in the milk are those of highly resistant hay and potato bacilli, and frequently those of a butyric bacillus, which germinate between 60° and 96° F. (15°-37° C.) and are capable of spoiling the milk.

For the destruction of the vegetative forms, a temperature of 158° F. (70° C.) is sufficient, and in some cases less, with an exposure of about fifteen minutes. In order to destroy spores, however, the heat in any case must attain or exceed 203° F. (95° C.).

The simplest way of maintaining water at these temperatures is by regulating the source of heat, for which purpose an automatic thermoregulator can be employed when gas is used.

This thermoregulator consists of a tubular vessel, half filled with mercury, and having a narrow tube inserted into it from the top. This narrow tube is open at the lower end and can be lowered to any desired depth. The gas flows through a connection into the outer tube above the mercury, but can only escape to the burner through the open lower end of the inner tube, the regulator being hermetically closed in every other part. The regulator is placed in the water, and as the temperature of the latter increases, the mercury expands and rises in the outer tube. When the desired temperature is attained, the inner tube is adjusted so that its open lower end nearly touches the surface of the mercury, whereupon any further rise in the temperature of the water will cause the mercury to ascend and shut off the gas supply, so that no further application of heat takes place until the water has cooled down again and the mercury has sunk far enough to re-admit the gas to the burner. This play is soon reduced to such narrow limits that the temperature of the water becomes practically constant. This is, briefly, the principle of the thermoregulator. In the usual forms, certain slight technical improvements are provided, such as a slotted opening at the bottom of the inner tube, so that the gas supply may be shut off

gradually and the adjustment to a given temperature facilitated.

Theoretically, at least, it seems feasible to control the temperature of the water by lowering the pressure and thus ensuring a lower boiling-point which cannot of course be exceeded so long as the partial vacuum is maintained. This arrangement would have the advantage that, as the result of ebullition, the liquids would become uniformly heated all through in a very short time. Another advantage, and by no means the smallest from the practical standpoint, is that the vegetative forms of bacteria are destroyed more rapidly in a boiling liquid than in a quiescent liquid of the same temperature. The reason for this difference is still obscure, and would take up too much space to be gone into here. In the case of water boiling under ordinary pressure, at 212° F., such difference cannot be detected, the destruction of the vegetative forms taking place too quickly to permit the time required being measured; and since there is no difficulty in killing the vegetative forms, no one would ever think of resorting to such a clumsy and difficult device as employing a partial vacuum.

2. Pasteurization.

In addition to boiling water, water that has been heated to any other temperature may be used as the source of heat for disinfecting substances containing moisture, especially foodstuffs. Such a method is largely used in the home and in factories for sterilizing preserves in tins or glasses, in the case of foodstuffs which cannot stand heating to 212° F.

This method is most frequently used for milk, and is generally known as pasteurization, after Louis Pasteur who invented it for improving the keeping properties

of milk and beer. It is true that the term is not restricted to the use of a water-bath at a temperature below 212° F. for the treatment of milk, but is generally applied to warming the liquid up to between 140° and 203° F., for the purpose of sterilization. In most cases, however, the water-bath is used as being the simplest means of producing a constant temperature.

As compared with "scalding" milk, the object of pasteurization is to prevent the changes set up in milk by boiling, and especially the appearance of the "boiled taste," and the formation of the skin consisting of coagulated lactalbumin. These changes occur at the coagulation temperature of albumin, 156° to 158° F., and therefore any method in which these changes are to be prevented, must work at a lower temperature. The question is now, what is pasteurization to effect? From the consumer's standpoint, the elimination of disease germs is the prime consideration. In this connection, experiment has shown that milk must be exposed to a temperature of 153° F. for half an hour in order that the disease germs present therein may be killed with certainty. These germs are mainly those of tuberculosis and of the diseases localized in the digestive tract: typhus, dysentery, and ptomaine poisoning. All other germs contained in milk are either more easily destroyed by heat, or else are harmless to the human subject. Any staphylococci, spores of anthrax or tetanus, that may be accidentally present do not act through the digestive tract; and it is also probable that the diarrhœa so frequently observed in infants during the summer time is not due to the action of bacteria which have survived the pasteurization process, but to some other cause.

Increasing the keeping properties of milk is a matter

that chiefly concerns milk dealers, the main point being to keep the milk from turning sour. This tendency is produced by a lactic bacterium, which is easily killed by warmth; and therefore turning sour, which is the preliminary to curdling, can be retarded by a short process of pasteurization, which enables this important foodstuff to be kept for some time in an apparently undecomposed state. This stability, however, is only apparent, since the putrefactive spores, including those of the hay and potato bacilli, which are not killed by pasteurization, germinate as soon as the conditions of temperature are at all favourable (about 59° F.), reproducing very rapidly and soon setting up putrefaction in the milk, the first indication of this condition being the development of an irritant flavour. The drawback from the purchaser's point of view is that he can no longer detect incipient putrefaction by the appearance of curdling, since the cause of this preliminary stage has been destroyed by pasteurization.

To make milk really stable by pasteurization it must either be strongly cooled at once after warming, and then kept at a temperature (ice box) which does not permit the germination of the spores; or else the heating must be repeated twice at intervals of twenty-four hours to give the spores time to germinate in the meanwhile (fractional sterilization). A rapid method of pasteurizing, in which the milk is heated to 203° F. for a short time, is also occasionally used; but it is not clear what advantages are obtained in comparison with scalding, since the milk both skins over and develops the "boiled" taste. Moreover, in all methods where heat is employed, the butter fat collects on the surface, and apparatus, often of a cumbrous character, is necessary in order to restore the normal emulsion.

3. Oil and Paraffin.

Of all the liquids employed in a heated condition for purposes of disinfection, those exerting a chemical action must be left out of consideration here. Among the remainder, only those of high boiling-point are suitable, since it will be evident that success in the destruction of spores can only be attained—in the case of anhydrous media—when a temperature of over 284° F. can be applied. Baths of oil and paraffin have found application in practice, their boiling-points being high enough to enable one to obtain temperatures up to 392° F. Of course they can only be used for articles that are free from water, since otherwise the water present would be violently converted into steam and ruin the articles. Materials unable to stand the great heat and direct contact with oil or paraffin cannot be subjected to this method of treatment. This excludes practically everything except metallic instruments, for which, indeed, the method—at least that employing oil—is excellently adapted for rapid disinfection. It is largely used for sterilizing the cannulæ of injecting syringes in polyclinical establishments where there is no time for boiling the instruments. In boiling oil, the whole of the germs are destroyed in a few seconds, so that a very effective and extremely rapid disinfection takes place. The only drawback of the method is the liberation of malodorous and acrid vapours, whose chief constituent, acrolein, is the cause of the smell of an extinguished candle.

II. Light and Other Rays.

Sunlight constitutes a disinfecting agent which is undoubtedly of extreme activity in Nature. Innumerable bacteria and protozoa are destroyed every day by

diffused, as well as direct, sunlight. This effect is due, not to the desiccating influence of the sun's rays—action of heat—but to that of the vibratory light rays.

It is well known that white sunlight is composed of a number of different kinds of light, which differ among themselves by their wave length and are exhibited individually to the eye in the colours of the rainbow. There is, however, in sunlight, another kind of light which is invisible to the human eye, but is capable of acting on a sensitized photographic plate, namely the so-called ultra-violet rays, which have the shortest wave-length of any, and are frequently known as the actinic rays. These rays are the chief germicide agents in light.

As a rule, only the superficially located bacteria are encountered by light rays; but these bacteria are also exposed in most cases to desiccation, and it is therefore difficult to decide what proportion of the success attained is due to either cause. If, however, desiccation be prevented by suitable means, it is found that spores are not affected by light rays at all, and that vegetative forms are influenced in different ways. For the performance of this experiment it is necessary to allow the light to impinge directly on the bacteria, whilst a closed vessel must be employed to prevent desiccation. Now a glass vessel prevents the transmission of the principal active components of the light, namely the ultra-violet rays; but plates of quartz, on the other hand, are permeable to these rays. In water, too, the light rays cannot act to any depth, the ultra-violet rays being absorbed in the upper strata of the liquid. Nevertheless, provided the water is perfectly clear, the action of light goes on to a depth of 1½ mm. below the surface of the water, though in rapidly diminishing proportion.

Moreover, experience shows that, in Nature, bacteria reproduce only in dark places; and the hygienic properties of light and air have been recognized for ages. Sunlight has been employed, and not unsuccessfully, for therapeutic purposes, especially in the treatment of superficial disease processes, lupus and the like; though it is doubtful whether the stimulation of the tissues does not contribute to the curative effect in greater proportion than the germicide action. Still greater success has been obtained by the Finsen light treatment; but even in this case it has not been proved that the action is one of sterilization.

The Röntgen rays seem to have practically no effect on bacteria; and it is only in rare instances that they have been found to retard the growth of cultures. In any event, the curative results obtained in the case of superficial infectious processes must be ascribed to some other cause than sterilization.

The emanations from radium greatly retard the development of bacteria; and an exposure extending over several days will even kill the spores of anthrax bacillus. However, since this bactericidal action is confined to the readily absorbed rays, the effect does not penetrate far, and therefore the employment of radium offers no advantages over that of sunlight.

III. Electric Currents and Mechanical Influences.

The other physical agencies suitable for application in the destruction of bacteria can only be briefly mentioned here, their practical importance being nil. The electric current—both continuous and alternating—is said to have a slight retarding effect on development, but not sufficient to kill bacteria when the auxiliary in-

fluences, heat, electrolysis and the production of ozone, are disregarded. Increased pressure again has but little effect on the growth of bacteria, these being still able to germinate in ordinary air when the pressure is raised to 800 to 1000 atmospheres. On the other hand, in the case of certain gases other than the ordinary atmosphere, increased pressure has a decided effect on bacteria. Apart from the adverse influence on growth exerted by gases like carbon dioxide or hydrogen on aerobic (air-loving) bacteria, some of the germs are destroyed in these circumstances, since they will no longer germinate when subsequently exposed to favourable conditions. Typhus, dysentery, and coli bacilli for example are killed by twenty-four hours' exposure to carbon dioxide under a pressure of one and a half to two atmospheres. On the other hand, hydrogen is powerless to injure in the slightest degree the most delicate germs, such as those of cholera, even with an exposure of twenty-four hours under a pressure of seventy-five atmospheres. In an atmosphere of oxygen, cholera bacilli perish in twenty-four hours under a pressure of half an atmosphere; typhus bacilli at thirty-five atmospheres, and coli bacilli at seventy-five atmospheres. It is thus apparent that the increase of pressure does not act *per se*, but only in consequence of the resulting increased chemical action (oxidation) on the substance of the bacteria. The method proposed by Berghaus for improving the keeping properties of milk by the action of carbon dioxide under heavy pressure has not found any practical application.

Whilst, experimentally, vigorous mechanical agitation is found to arrest bacterial growth, gentle agitation has a stimulating influence; but all these observations possess nothing more than a certain theoretical interest.

CHAPTER III.

CHEMICAL DISINFECTION.

CHEMICAL disinfection implies poisoning the germs of disease. The poisons acting upon bacteria and protozoa penetrate through the envelope of the organism and destroy its life in consequence of their specific toxic action which consists in effecting a change of condition (coagulation) of the protein, or exerting some other influence on vitally important substances. These poisons act solely in the liquid condition, even when employed in the solid or gaseous form; and it is only such portions as are in solution, either in the immediate environment of the bacteria or within the bodies of the latter themselves, that can be credited with disinfectant action.

Since the corpus of the micro-organism is a cell, analogous in many respects to the corporeal cells of higher organisms, it will be evident at once that chemical disinfectants are capable of producing poisonous effects on the higher organisms as well. It is true that these toxic effects on corporeal cells differ, often very considerably, from the disinfecting action, since each cell has its own specific chemical affinities. Thus, for instance, serious corporeal poisons, such as strychnine, atropine, etc., have not the slightest effect on bacteria, whereas hydrogen peroxide kills bacterial cells very quickly, but leaves corporeal cells almost unaffected.

The physiological action of the various disinfecting agents is a matter that is immaterial from the standpoint of disinfection. We shall rest content with ascertaining the effect of the chemical treatment, and draw up regulations for practical application accordingly. It is naturally impossible to test the action of every disinfectant on all species, races, and stocks of bacteria; but it is sufficient to make definite typical tests, in the presumption that the disinfecting action on all other disease germs can be deduced therefrom. This standpoint is quite justified, for in treating a large series of micro-organisms with various disinfectants it is found that certain well-defined species are killed in a relatively short time, and others in a relatively longer time, by all disinfecting agents. Some species, therefore, are very sensitive to disinfectants, others comparatively so, and others again have a high power of resistance. It is true that accurate investigation will reveal occasional specific powers of resistance towards certain disinfectants—such instances standing out prominently from the general run; but no practical importance attaches to such cases as yet. Certain bacteria, the resistance of which toward the usual disinfectants has been the subject of numerous investigations, afford a means of testing the action of a disinfecting agent; but, as already mentioned, it is always essential, in precise investigations, to make a comparison by means of a known method of uniform action. When a more powerful disinfection, involving the killing of spores, is in question, steam at 212° F. is preferably taken as a standard. This effect can be accurately determined, owing to the constancy of the temperature, rapidity of penetration of the article under treatment, and accuracy of timing the test. The apparatus devised by Ohlmüller

for this purpose consists of a glass flask, in which steam is generated, surmounted by a T-tube, into one end of which is inserted a thermometer, whilst a stopper attached to a chamber for holding the articles under treatment, and fitted with an exhaust pipe for the steam, is pushed into the other end (Fig. 8).

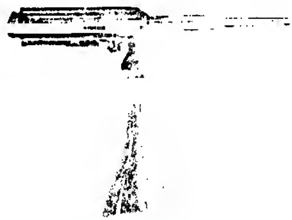

FIG. 8.—Ohlmüller Spore Tester.

For less drastic disinfection, it is usual to employ as the standard of comparison a disinfectant of known and constant action, e.g. carbolic acid, this affording the advantage that the standard can be modified by dilution.

There is no uniform method for testing a disinfectant, the operation being usually performed in scientific laboratories, and the details left to the choice of the operator. However, in order to afford an approximate idea we will quote the conditions of the first experiments given by Koch in his work published in 1881. A suspension was prepared from a culture of anthrax bacillus several days old, and consisting almost entirely of ripe spores, thin silk threads, 1 to 2 cm. long, being dipped into this suspension until thoroughly saturated, and then dried. These test specimens, carrying numerous anthrax spores in the dried state, were first tested for their power of resistance, by steaming them at 212° F., some of them being exposed thereto for half a minute, others for one minute, etc., and then transferred to a nutrient medium. Assuming that the test specimens steamed for two minutes still germinated to

colonies, whereas those exposed for two and a half minutes remained sterile, the resistance of all the test specimens of the same race would be two minutes; and the test specimens could be employed for testing the action of disinfectants. In this manner, however, spores alone could be treated; and in order to test vegetative growths, which will not stand desiccation, these must either be suspended in the disinfecting liquid direct, or else caused to adhere on linen rags in a semi-moist state. Such, broadly, are the methods of preparing the test specimens, though, in practice, numerous modifications have to be adopted.

With regard to the testing of chemical disinfectants, it must be premised that an erroneous idea may be formed in many cases unless the disinfecting liquid has been thoroughly eliminated from the test specimens before transferring these latter to the nutrient medium. Without exception all chemical disinfectants have the property that even in a very dilute condition they retard the growth of bacteria, without killing the latter entirely. If, however, the traces of disinfectant accompanying the test specimens into the nutrient medium be afterwards eliminated, the micro-organisms still surviving will be able to germinate.

Apart from the question of concentration, the action of a disinfectant depends, biologically, on the resistance of the micro-organisms and on the temperature; and physically, on the capacity of the articles under examination to absorb moisture. The concentration of the disinfectant stands in direct relation to its action, within certain limits, but if the concentration be very high, the action is only slightly increased, whilst conversely, extreme dilution weakens the effect but slowly—though this is not always true, the effect alter-

ing rapidly, up or down, when the concentration is modified. The resisting power of the micro-organisms has already been discussed; and so far as the temperature is concerned, its influence is based on the physiological vital processes of the micro-organisms. An organism which is cooled below its optimum temperature, gradually passes into a state of coma, in which the processes of nutrition and reproduction are almost or entirely suspended, according to the degree of cooling given. In this condition the bacterial cell has a correspondingly low tendency to undergo chemical changes, and the disinfecting effect diminishes in intensity. On the other hand, the cell is far more open to chemical attack at its optimum temperature, at which all the vital processes, and therefore also the chemical reactions, go on best; whilst, as the temperature is raised above this point, the tendency of the cell to decompose increases and it falls an easier prey to the destructive action of poison. Hence the action of disinfectants is facilitated by every rise in temperature. The physical dependence on the hygroscopic capacity is self-evident. For instance, the spores of mould fungi will float on the surface of any disinfectant liquid, because they cannot be wetted by water unless they have been previously treated with alcohol.

The number of chemical disinfectants is extremely large, and nearly every group of chemical substances includes members capable of injuring micro-organisms. In practice, however, only a relatively small number of chemicals come under consideration, it being necessary to exclude all that act only in a high state of concentration, as well as those which unduly corrode the materials to be disinfected, or which are too expensive. To describe, or even mention, all the various chemical disin-

fectants would take up too much space; and it is, moreover, quite sufficient to treat of the most important members of each group.

I. Liquid Disinfectants.

The only possible way of classifying chemical disinfectants is to adopt the same grouping as is employed in chemical science. These groups will be given *seriatim*, without going into their chemical properties; and, in addition, a few disinfectants from different groups will be classified together in accordance with their method of action.

(*a*) *Native Metals.*

Although native metals are only very slightly soluble in water—the amounts being imperceptible even with very refined methods of examination — nevertheless, certain of them are endowed with the power of destroying animal and vegetable cells. If fragments of certain metals be introduced into cultures of bacteria in nutrient media, there will be formed around each fragment of the metal a more or less wide zone in which no bacterial growth can proceed, this zone remaining sterile even after the metal has been removed. Hence the effect must be ascribed to dissolved particles of the metal. When this passing into solution is facilitated by any means, for instance by establishing electrical conduction with another metal of opposite electrical activity, the disinfectant action is considerably increased. In addition to this (normal) poisonous action of metals, another method of action has been observed, which possesses a high scientific interest, and will perhaps attain practical importance at some future time. This action, which was first discovered by C. von Nägeli,

differs essentially from simple toxicity, since the symptoms of approaching dissolution exhibited by the algae examined by that worker differ from those appearing when any other method of destruction is employed. This so-called oligodynamic effect occurs in cases of extreme dilution, for example, when a piece of copper the size of a farthing is left for a few minutes in a quart of water containing vegetable cells. Similar action is exerted by metallic salts, such as corrosive sublimate, in a state of extreme dilution (1 : 1,000,000). Another point which distinguishes this from ordinary toxic action is its great susceptibility to external influences, any addition of common salt, organic matter, or even the presence of a large number of vegetable cells, preventing it completely.

In the case of pathogenic germs, experiments on this point have furnished the following results:—

Resting forms are not affected at all by the oligodynamic action of metals; though vegetative forms are killed in one to three hours if fragments of active metal be immersed for a short time in the pure water used for the suspension. The most powerful metals in this respect are copper and its alloys (brass), next in order coming zinc and iron, whilst lead and nickel do not produce the slightest effect. American workers (according to Krämer) have proposed to disinfect filtered drinking water by immersing copper plates; and since only the easily destroyed vegetative forms of bacteria are here in question, and the extremely minute quantities of copper passing into solution do not appear capable of having any toxic effect on the human subject, the suggestion is worthy of attention.

The ordinary toxic action of metals—which, according to Thiele and Wolff, is confined to copper, mercury,

and silver, all the other metals examined (magnesium, aluminium, iron, zinc, lead, selenium, palladium, platinum and gold) being quite inert—is, however, also capable of practical application. Experiments with intestinal germs in the environment of men and animals have shown that such bacteria are to be found on all objects with which the hands are liable to come in contact, except such as are made of copper or brass. Therefore, since it has been demonstrated that infectious diseases are frequently communicated through the hands, the exclusive use of a powerfully antiseptic metal, such as copper or brass, for making all handles, door latches, stair balusters, etc., is a hygienic precaution which can be relied on to be successful in the prevention of infectious diseases.

(b) *Acids and Alkalis.*

Since the nutrition and reproduction of micro-organisms are dependent on certain chemical reactions, varying between somewhat narrow limits, all strong acids and alkalis adversely affect the vital processes. This effect of increased acidity or alkalinity is, however, far surpassed by the specific antiseptic power possessed by many acids and alkalis, especially those of an inorganic character, by reason of the active atoms they contain.

Among the acids, hydrochloric acid in particular, then oxalic acid, and also sulphuric and nitric acids, will kill all germs in a very short time, whereas the antiseptic properties of other acids, such as acetic and citric acids, are only slight. Their highly destructive action on most objects, however, stands in the way of their employment in practice, and consequently the cheapest of the strong acids—hydrochloric acid and sulphuric acid—are rarely used. The employment of

acetic acid or citric acid for disinfecting drinking water suspected of infection by the germs of cholera, typhus, or dysentery may have to be considered occasionally in uncultivated districts, but is attended with the drawback that it takes at least one to two hours. Broadly speaking, the action of alkalis is less powerful. Caustic potash is the strongest, carbonate of soda being a very poor agent, and ammonia almost entirely devoid of action. In practice, the strong alkalis will only occasionally come under consideration for use as disinfectants, since they corrode most articles that require treatment. An exception is afforded in the case of slaked lime, which is extensively used in practical disinfection. Milk of lime is prepared by treating burned lime with about its own weight of water, which causes it to crumble down to a dry powder, which can then be dissolved in a fourfold quantity of water. The first stage of the process is accompanied by a considerable disengagement of heat. The resulting milky fluid, which is renowned for its caustic action, contains 20 per cent of calcium hydroxide, and is diluted, as required, for use. Fæcal matter is disinfected by mixing with an excess of a 2 to 10 per cent solution and leaving it to stand for an hour. The diluted liquid is also used for disinfecting sewage liquor, as a wash for infected walls and utensils; and one may be quite certain that, provided a large excess of the caustic lime be used, the cholera, typhus, and dysentery germs in question will be completely destroyed in less than an hour.

Among the weaker alkalis, the alkaline soaps should be mentioned. These really serve merely for dissolving and removing the superficial layers of the epithelium together with the adherent germs—mechanical disinfection—but in addition the soaps at the same time

possess slight germicide properties, which are sufficient to destroy the majority of vegetative forms.

(c) *Metallic Salts.*

The group of metallic salts is of considerable importance, and comprises the most powerful disinfectants known. The chief representatives of this group are the compounds of mercury and those of silver.

Corrosive sublimate (mercury dichloride, $HgCl_2$) destroys the vegetative forms of bacteria in a few minutes, even when diluted down to 1 part in 10,000; and the spores of bacteria possessing medium powers of resistance, such as anthrax spores, are killed within two hours by a 1 : 1000 solution. A similar action is exerted by silver nitrate (lunar caustic, $AgNO_3$). However, like many other disinfectants, all metallic salts depend greatly on the other substances present in the solution, and also on the solvent, because their disinfectant power is influenced by their degree of electrolytic dissociation. For this reason they act much less powerfully in an alcoholic solution, and not at all in a fatty or oily medium. The dissociation is also modified by additions of other reagents. For instance, the dissociation of mercury dichloride is lessened by sodium chloride—both of them containing chlorine atoms—whereas the power of the originally much weaker salt, mercury oxycyanate, can be so far increased by the addition of sodium chloride as to approximate closely to that of sublimate. The oxycyanate, as also another preparation of mercury, sublamine (mercury ethylenediamine sulphate) which has analogous properties, were therefore introduced into practice some years ago as substitutes for sublimate, owing to their lower cor-

rosive action, though they have never succeeded in ousting it completely. Even at the present day, all three retain their spheres of usefulness, and are appreciated for washing doors, windows, flooring, etc., on account of their lack of smell. They have never been adopted for metallic articles, being precluded by their corrosive action, although it was formerly claimed that the two substitute preparations did not corrode metal. On the other hand, they have almost gone out of use for disinfecting the performer or the subject of an operation, in which sphere they predominated for nearly twenty years. Although it has long been known that mercury compounds are almost inactive in presence of protein—which occurs in all corporeal elements—and that they also roughen and crack the epidermis, so that it became increasingly difficult to disinfect the hands of the surgeon, mercury preparations have even been introduced into the disinfection recipes of the midwife and doctor's assistant. This is the more to be regretted in view of the facts that, on the one hand, the action of mercury salts for disinfecting the hands is imperfect, for the reasons already given, and that, on the other hand, the highly poisonous properties of the pastilles may lead to considerable danger through carelessness or ill intention. One or two sublimate pastilles will destroy human life, producing symptoms of acute intestinal inflammation and cramp, or chronic renal inflammation and intestinal ulcers.

Notwithstanding their powerful disinfectant properties, the silver salts have not made headway in practice, their chief representative, silver nitrate, being liable to decompose in contact with air, whilst they are too expensive for general use. The salts of gold, copper, and iron are far less effectual than those men-

tioned before, and therefore do not come under consideration for practical purposes.

(d) *Phenols.*

This generic term includes all the chemicals allied to true phenol (carbolic acid), which form a very important group of disinfectants. Carbolic acid has gained its prominent position in practical disinfection through its very stable chemical constitution, and from the fact that the few compounds it is capable of forming are equally powerful as disinfectants. Although its action is not so strong as that of sublimate, it scores by the circumstance that it remains uninfluenced by the presence of salts, acids, alkalis, and even protein. Alcohol alone has an adverse effect on the action of carbolic acid; and in fact so much so that solutions in absolute alcohol are completely inert. Carbolic acid, which is soluble to the extent of 7 per cent in water, kills vegetative forms in a few minutes at room temperature, though even when used in its most concentrated form it takes several hours to destroy the vitality of spores, even the pure acid having no greater effect in this respect. On the other hand, its action can be increased in a very important degree by raising the temperature; so that spores can be killed in five to twenty hours with a 3 to 5 per cent solution of carbolic acid at 86° to 104° F. This acid is unsuitable for disinfecting the hands, or the seat of an operation, owing to its powerful corrosive action and paralysing effect on the dermal nerves. Its toxic action consists in the formation of a whitish scurf (with the attendant consequences) and also, mainly, an acute form of intestinal inflammation, renal inflammation, loss of consciousness, twitching of the muscles, etc. For inanimate objects it

is rather expensive, and is mostly replaced by its analogues, the cresols and their compounds. The three cresols, meta-, para- and orthocresol, are in themselves too sparingly soluble (0·5, 1·8 and 2·5 per cent respectively) to exert any powerful disinfectant action; but their solubility can be largely increased by the addition of strong acids or of alkaline soaps, which raise them to the category of the strongest disinfectants. The compound of crude cresol with sulphuric acid—commercially known as "Sanatol" or "Automors"—and other compounds (e.g. bacillol) of the same class, are powerful, but are attended with the drawback of being poisonous and of destroying colours, varnishes, etc., in consequence of the large amount of acid they contain. Far greater popularity is enjoyed by the cresols which have been dissociated by means of soap solutions, namely "Creolin" and "Lysol," which are very much alike. The last named especially—which furnishes clear solutions in pure water—is very widely used, dissolving very readily and having a lubricating effect on the skin without making it insensitive. Its disinfectant power is superior to that of carbolic acid, even in a 1 to 2 per cent solution, and consequently this preparation has retained a prominent position for many purposes, for example for disinfecting catheters in gynæcological practice. Unfortunately, it has also acquired considerable popularity among would-be suicides. The toxic symptoms resemble those of carbolic acid poisoning.

(e) *Alcohols.*

The alcohols—of which methyl, ethyl, and propyl alcohols come under consideration here—are still the subject of scientific discussion so far as their disinfec-

tant properties are concerned. That they are endowed with a by no means small power of disinfection is indubitable, but the scientific experiments performed in this connection have furnished widely different results in point of detail. On the whole it has been ascertained that solutions above 10 per cent in strength kill all vegetative forms; and that this action increases in power up to solutions of 40 to 50 per cent strength, beyond which limits it again declines. Boiling alcoholic mixtures exhibit increased efficiency within the same limits, but also fall off considerably in concentration between 50 and 100 per cent (methyl alcohol above 50 per cent, ethyl alcohol above 80 per cent, and propyl alcohol above 90 per cent). Hence, the absolute alcohols act less powerfully than solutions in equal parts, a circumstance which is attributed to the precipitating influence of the concentrated alcohols on protein. The idea is that a stratum of coagulated protein is formed on the surface of the micro-organisms and prevents the penetration of the alcohol; and, as a matter of fact, the disinfecting power of absolute alcohol can be considerably increased if the formation of the stratum of protein be prevented by powerfully agitating the disinfecting liquid. This, at least, is the case with test-tube experiments. In practical disinfection, absolute alcohol and the officinal spiritus rectificatus have enjoyed considerable popularity, both alone and in various combinations, such as alcoholic solutions of soap, tincture of iodine, etc. Nevertheless, alcohol was formerly employed merely as an intermediate stage in the disinfection of the hands, being credited with only a moderate power of disinfection in consequence of the experiments referred to above. It is only within the last few years that treating the hands with concentrated alcohol for a

few minutes, without any previous washing with soap and water, furnishes much better results than the older methods of disinfecting in preparation for operations, for which purpose scrubbing with soap and hot water, removal of fat with ether, and washing with strong solutions of chemical disinfectants (sublimate) for twenty to twenty-five minutes, were formerly employed. The effect of disinfection with alcohol alone has been explained by the observation that absolute alcohol causes micro-organisms to adhere so firmly to the skin that they cannot be detached even by immersion in water for several hours. No doubt this adhesion is accompanied by a certain degree of disinfection, since practically no bacterial development can be detected when the epidermal scales scraped off the skin with a knife after the use of alcohol are transferred to nutrient media. This observation also explains the action of alcoholic soap solutions, iodine tincture and other alcoholic combinations, though it should be noted that the effect of the alcohol is lessened by the presence of soap and other adjuncts, iodine forming, however, an exception. The ordinary form in which alcohol is used is that of rectified 95 per cent spirit. Satisfactory results can also be obtained with 80 to 90 per cent spirit denatured with pyridin bases so as to unfit it for internal consumption. The employment of alcohol vapour will be dealt with later (p. 92).

(*f*) *Hydrogen Peroxide and other Oxidizing Agents.*

All substances which readily part with oxygen have an oxidizing effect on organic materials, and therefore on micro-organisms. Among the most powerful of these substances are the so-called per-compounds, which are surcharged with oxygen. Since they usually act solely

by oxidation, they are innocuous to the human organism, unless they contain some other poisonous constituent. Hydrogen peroxide (H_2O_2) possesses very powerful bactericidal properties. When diluted to 0·05 per cent it destroys all vegetative forms in a few minutes. Spores are less readily attacked, but even in respect of these, solutions of 1 to 3 per cent strength are quite as effective as the better-known disinfecting agents, such as carbolic acid. The only pure hydrogen peroxide is Merck's 30 per cent solution (perhydrol) in paraffined flasks. This is very expensive; but there is a cheap commercial 3 per cent solution which is treated with some mineral acid (usually sulphuric acid) to render it stable; it has the advantage of not only disinfecting, but also cleansing and deodorizing (by the oxidation of organic particles), as well as bleaching, on which account it is beneficially used by hairdressers for cleansing brushes and combs. It may also be applied to advantage—in a dilute condition, down to 1 : 10,000—for disinfecting drinking water; only one must wait for half an hour until the disinfecting action is completed and the hydrogen peroxide has decomposed into water and oxygen. True it is not in itself poisonous, but it sometimes has an irritant effect and a somewhat disagreeable taste. The latter generally remains behind to some extent, in which case it is due to the mineral acid, the small quantity present being, however, harmless. Hydrogen peroxide solutions of 1 to 3 per cent strength have latterly become very popular as a mouth wash, and, so far as their disinfectant properties are concerned, are preferable to most other liquids of this class. Certain metallic peroxides too possess an undoubtedly similar disinfecting power, and are occasionally sold for disinfecting drinking water (e.g. cal-

cium peroxide, magnesium peroxide). Their oxidizing action is, however, inferior to that of hydrogen peroxide, though, in the case of the lime compound, it is assisted by the calcium hydroxide formed. Magnesium peroxide also furnishes good results, but its use must be deprecated, since it introduces objectionable quantities of magnesium into the drinking water.

Potassium permanganate has a powerful disinfecting action even on spores, anthrax spores of average powers of resistance being killed in fifteen minutes by a 4 per cent solution, and in forty minutes by one of 2 per cent strength. Owing to its cheapness this admirable disinfectant, which is also renowned as a deodorizer, is suitable not only for disinfecting inanimate objects, but also for treating wounds, corporeal cavities, and, when suitably diluted, as a mouth wash.

There are, in addition, a whole series of per-compounds, some of which (persulphates and peroxides) are very powerful disinfectants, but as these have not yet met with any important practical application, they need not be gone into here. Ozone will be dealt with under gaseous disinfectants (q.v.).

(g) *Antiformin.*

A highly interesting and recently discovered disinfectant is Antiformin. This is the well-known Eau de Javelle (potassium hypochlorite) dissolved in an excess of caustic potash. Formerly employed only in breweries for cleansing fermentation vessels and beer pipes, its disinfectant properties were discovered by Uhlenhut and Xylander. These properties consist in the faculty of dissolving bacteria in a few minutes. All pathogenic germs, with the exception of the tubercle bacillus and ripe anthrax spores, are dissolved in two and a half to

five minutes by a 2 to 5 per cent solution of Antiformin. Unripe anthrax spores, i.e. those in twenty-four hour cultures on agar-agar, dissolve at the end of seven hours, whereas the ripe spores remain undissolved after twelve hours. The tubercle bacilli, and the allied acid resisting bacilli, are protected by the already mentioned waxy constitnent of their envelopes against numerous injurious influences, as also against the action of Antiformin, remaining capable of reproduction, though in an enfeebled state, after treatment with that agent for several hours. On this account, Antiformin is well adapted for the isolation of tubercle bacilli from the numerous bacteria with which it is always accompanied in sputum, with a view to the preparation of pure cultures of the organism. Apart from the two exceptions mentioned, Antiformin constitutes an excellent disinfectant, the usual strength being a 5 per cent solution. Its chief advantage is that it is able to dissolve (not coagulate) protein and mucus present in liquids; and it is therefore primarily adapted for the disinfection of dejecta in cases where the annihilation of tubercle bacilli is not regarded as essential.

There are numerous other substances exhibiting a certain power of dissolving bacteria, for example sodium taurocholate, but these are of no practical importance.

(*h*) *Chlorine, Bromine and Iodine.*

These three halogens form an interesting, if not very highly important, group of disinfectants. Chlorine and bromine, which are gaseous at the ordinary temperature, and give off a very penetrating smell, belong mainly to the series of gaseous disinfectants; but their solutions must be dealt with now in connection with iodine. Chlorine is the most powerful disinfectant

known, a 0·01 per cent solution being able to destroy the most obstinate spores in a few seconds. Bromine is only slightly inferior to chlorine; but both have an extremely destructive effect on all organic matter. Clothing and body linen, for instance, fall to pieces after very short treatment, all colours are destroyed, and both elements are extremely poisonous to man. Hence neither chlorine nor bromine solutions are used in a pure state, though the action of the "Bleaching powder" (or "chloride of lime") frequently used for disinfecting closets, is based on the liberation of free chlorine. This powder, which consists of calcium chloride and calcium hypochlorite, when acted upon by an acid—even the small quantities of carbonic acid present in the air—decomposes with formation of hypochlorous acid, which in turn gives off free chlorine.

Iodine, which attacks organic matter less powerfully, and is almost non-poisonous, is also inferior in disinfecting power, though for practical purposes it is effective enough. In the form of iodine tincture, it is now largely employed for disinfecting the skin previous to operation, and for sterilizing catgut, though the action of the iodine is probably exceeded by that of the alcohol. Iodine dissolved in potassium iodide has also been used for the same purpose, though with less effect. The deep brown stain is also a drawback. The action of free iodine is also the basis of the surgical application of iodoform, from which iodine is liberated by the action of corporeal ferments since this iodine alone possesses bactericidal properties, iodoform *per se* being inoperative. It is on this account that the known activity of iodoform is equalled by only few of the numerous medicaments which have been proposed as substitutes for this malodorous substance—in fact only by such as

also contain iodine, liberated in approximately the same manner.

(i) *Formalin.*

Formalin is the 40 per cent solution of a gas, formaldehyde, which has a highly penetrating smell, but is relatively innocuous. Its real importance is as a gaseous disinfectant, its use in which condition is described fully later on (see p. 74). As an aqueous solution, the chief action of formaldehyde is to restrict the growth of bacteria, which are prevented from germinating by solutions as weak as 1 : 20,000. Much stronger solutions of the gas, however, are required to actually kill bacteria, though 4 per cent is a sufficient strength to destroy all vegetative forms and the majority of resting forms in less than half an hour. The disinfectant properties are heightened considerably by raising the temperature. Formalin has been used as a food preservative; but its employment for this purpose is prohibited in Germany, on account of its tanning action on corporeal cells when taken internally. Even in a state of extreme dilution, its presence can be identified by the characteristic penetrating smell. For disinfecting the skin and hands it is also unsuitable, its tanning action rendering the skin hard and dry. Attempts have been made to obviate this drawback by incorporating formaldehyde with concentrated alcoholic solutions of soap; and a preparation of this kind (Lysoform) is largely used as a disinfectant, for which purpose it is equivalent to 3 to 5 per cent carbolic acid. The tanning action on the skin is almost entirely prevented. Another preparation, Morbicid, acts in a similar manner.

(k) *Preservatives.*

Owing to the keen struggle carried on by the Legislature of nearly every country against the use of injurious chemicals for preserving foodstuffs, certain branches of industry are continually bringing new "preservatives" on the market. The action of these new preparations is hardly distinguishable from the old, prohibited preservatives, such as sulphurous acid, boric acid, salicylic acid, benzoic acid and compounds of same. When used in the quantities prescribed, all of them have a certain retarding influence on the growth of bacteria, but never to such an extent as to prevent putrefaction from setting in a little later than usual. The danger of preservatives lies, on the one hand, in the fact that they mask putrefaction phenomena which would otherwise be detected by the eye and nose, and on the other in that the cumulative consumption of foodstuffs preserved in this manner injures the organism. The true disinfecting power of these preservatives is very slight, so that even the germs of lactic bacteria, which have a very low power of resistance, will reproduce actively after initial retardation in milk heavily dosed with preservatives.

(l) *Volatile Disinfectants.*

This category comprises a number of substances belonging to a variety of chemical groups, and having in common the property of being only sparingly soluble in water and remaining solid or liquid at ordinary temperature, but volatilizing readily. The chief substances of this class are: chloroform, thymol, toluol, oil of turpentine, and a few ethereal oils.

Chloroform acts chiefly as a preservative, and is often used in the laboratory to preserve blood serum and other nutrient media, the proportion added being about 1 to 2 per cent. The chloroform settles down to the bottom, and the amount of volatile constituents which it cedes to the supernatant liquid is, though small, sufficient to prevent any bacterial growth. This effect is not destroyed by the large protein content of the liquid. Before the liquid is used, the chloroform can be readily expelled by warming at 50° to 60° C. for an hour. A similar liquid is toluol, which is, however, a far more powerful bactericide, and is in turn surpassed by thymol, which does not melt below 51° C. The addition of a crystal weighing less than 1 gramme to 1 litre of a liquid liable to putrefaction, will ensure it keeping for weeks, or even months. At the same time the weight of the crystal hardly diminishes at all, thymol being very sparingly soluble in water. In alcoholic solution its action is not so powerful; but when the concentrated vapour of thymol is used in conjunction with steam, say in vacuo, the disinfectant power is approximately equal to that of formaldehyde. Oil of turpentine, the ethereal oils of mustard and origanum oil, possess not inconsiderable disinfectant properties. Oil of turpentine now finds practical application for disinfecting and deodorizing, and also for internal disinfection—inhalation by sufferers from pulmonary complaints attended with malodorous sputum, e.g. inflammation of the lungs. On the other hand the disinfecting properties of other volatile substances, such as camphor, menthol, naphthalene, are very small, though they are of some importance as preservatives.

Finally, mention should here be made of several tar products: aniline, creosote, ichthyol and guaiacol.

TABLETS.

A description of the various members of different groups of disinfectants which are now marketed in tablet form is justified on the grounds that tablets constitute the most important form for many practical purposes, the actual composition of the tablets being a secondary consideration. This form is superior to powders and liquids because the proportions can be accurately weighed out in the process of manufacture, so that solutions of a certain percentage strength can then be prepared even by entirely unskilled persons. Convenience in packing and transport are also advantages of the tablet form. An essential condition, however, is that the tablets shall be stable. Of late, manufacturers have endeavoured, with more or less success, to send out all kinds of disinfectants in tablet form; and the advantages of these have been utilized, not only in clinics and disinfecting installations, but also by private persons who use disinfectants more rarely.

1. Sublimate and Sublimate Tablets.

Angerer's sublimate pastilles are the oldest form of disinfectant in weighed out quantities, and consist of 4·6 per cent of corrosive sublimate, together with common salt and an addition of eosine to colour the solution and thus prevent accidental poisoning. The common salt is added to prevent the decomposition of the sublimate; but, according to Kroenig and Paul, the amount used might be reduced one-half without loss of utility. Since the pastilles contain the disinfectant in an unaltered condition, they are just as effective as the corresponding solution of the salt. The

tablets, weighing 1 or ½ gramme, are sold in a black wrapper bearing the imprint of a skull in white, and must be protected from moisture, being very hygroscopic.

Sublamine, which, as already mentioned, is preferable to sublimate for some purposes, can be pressed into durable pastilles without any added matter except eosine for colouring. Its action has already been described.

2. Phenol and Cresol Tablets.

The oldest form of carbolic acid tablets was prepared by mixing pure carbolic acid—liquefied by heat—with 40 per cent of hard soap, the mass being formed into tablets when cold. These tablets did not keep well and had to be stored in glass tubes. They melted at 107° F. and gave a cloudy, but complete, solution in water, the disinfecting properties being apparently unaffected by the adjunct. Though they served their purposes for many requirements, they never succeeded in finding general application.

Carbolic acid "Phenostal" tablets are a combination of carbolic acid and oxalic acid (diphenyloxalate), two parts of the former to one of the latter. Owing to the powerful disinfectant properties of the oxalic acid, these tablets are one and a half to four times as effective as carbolic acid of equal concentration. This phenostal has the further advantage over carbolic acid that it is less poisonous, has not such a caustic action, and does not precipitate protein on absorption. The tablets are coloured with a little fuchsine, and cost about twice as much as carbolic acid of equal efficiency. The new carbolic acid tablets of the German

makers of "Phenostal" consist of phenol and potassium phenolate, and thus contain 90 per cent of phenol. The mass is a white powder which does not melt below 224° to 226° F., and is therefore suitable for use in the tropics. The tablets themselves are stable and readily soluble. The solution is not corrosive, and the bactericidal effect is slightly below that of carbolic acid. The price is still very high.

The same makers also vend lysol tablets, containing paracresol 75 per cent, hard soap 15 per cent, talc and bole 5 to 7·5 per cent.

The tablets have an evil smell, which is only partially masked by perfumes (cumarin). The action corresponds to that of a solution containing the same amount of paracresol; but since paracresol has a lower disinfecting power than its isomers, the effect of lysol tablets can in general merely be designated as adequate. Cresol tablets, made by the same German firm, are a compound of potash and metacresol (metakalin) which melts at 178° F., and consists of 70 per cent of metacresol, together with a little talc and bole. These two additions improve the keeping properties of the tablets; but as the latter are still liable to deliquesce, owing to their hygroscopicity, they have to be protected from moisture. This latter property at the same time ensures ready solubility. Their disinfectant properties are higher than those of lysol tablets, metacresol being superior in this respect to paracresol.

The "Segerin" tablets are also compounds of cresol and soap. The brown tablets consist of 50 to 55 per cent of metacresol and have very good keeping properties, for though they are rather soft when newly

made, they harden in storage. Nevertheless, they dissolve readily and are claimed to be superior to Liqu. cresol. sapon. of equal concentration. The black tablets, which are made of a mixture of the three crude cresols, are said to be equally powerful with the brown, since they contain at least 30 per cent of metacresol and over 20 per cent of the other two forms.

II. Gaseous Disinfectants.

The ideal disinfectant is a gas of great antiseptic power and capable of uniform distribution in space. This latter result is opposed by the considerable difficulty that all spaces are filled with a gas—atmospheric air—which has to be displaced in some way or other, or else mixed with the disinfecting gas. Of these latter there is no scarcity, but their practical employment is opposed by difficulties which, for the most part, are insuperable. Chlorine and bromine are the most powerful gases of this kind, but they enter too quickly into combination in the air to allow themselves to be distributed in anything like an efficient manner. Moreover their destructive action on colours and fabrics puts them out of court for practical use; and since hydrogen, oxygen, and carbon dioxide are too inefficient, the number of gases suitable to act as disinfectants is very small.

(a) *Sulphurous Acid and Carbon Monoxide.*

Sulphurous acid (sulphur dioxide) which is formed by the combustion of sulphur, is well known from its penetrating smell, and has been used from time immemorial for disinfecting (fumigating) casks and vats. For this purpose the physical properties of the gas are

comparatively favourable, its composition being so stable that it mixes with air without change. In course of time it penetrates deeply into the pores of the articles under treatment, and, in presence of a high proportion of humidity, is a capable bactericide. Its poisonous properties, however, restrict its use considerably; and many articles suffer damage by its bleaching effect on

FIG. 9.—Clayton Apparatus.

colours, and the ineradicable stains caused by deposition of sulphur.

The only process in which fumigation with sulphur has attained any great importance is in disinfecting plague ships by means of the Clayton apparatus (Fig. 9). The gas is generated in this apparatus by burning sticks of sulphur, and is blown into the cabins, etc., of the ship suspected of being infected with plague. Owing to its content of anhydride, Clayton gas is superior in disinfecting power to pure sulphur dioxide;

and when mixed, in the proportion of 5 to 8 per cent, with the air of a room, will infallibly destroy the vegetative forms of typhus, cholera, dysentery, and above all, plague, provided the germs rest on surfaces to which the air can gain access. As already mentioned, the gas penetrates for a certain depth into cavities and pores, but this property must not be confounded with the effect resulting from the actual displacement of the air in the pores by the disinfecting gas. In the case of tubercle bacilli and resistant staphylococci, the disinfecting action of Clayton gas in the above proportions is uncertain.

The main purpose, however, of the Clayton apparatus is the destruction of rats, which are very dangerous transmitters of plague. Five per cent of Clayton gas in air will infallibly kill rats, mice, cockroaches, bugs, fleas, gnats, etc., in a few seconds; and even when only 1 per cent of the gas is present, the rats are no longer able to reach their hiding places. As the Clayton apparatus blows an ample supply of gas into the rooms in a very short space of time, all the rodents which happen to be at large are usually killed at once, though the gas is not always able to penetrate into the remotest recesses in the prescribed time of four to five hours.

It may also be mentioned that sulphur fumes have been successfully used for killing the yellow-fever fly in districts where that disease is prevalent.

The dark side of disinfecting with sulphur fumes is, as already hinted, that many articles are damaged by sulphur (fabrics are stained, and foodstuffs absorb the sulphur); also that the hiding places of rats are not penetrated by the fumes. To overcome this defect, Nocht and Giemsa have proposed to use a gas containing about 5 per cent of carbon monoxide, generated

very cheaply and in a manner not liable to give rise to explosions, by burning coke in a special apparatus.

The gas has no real disinfectant power, and the plague bacilli must be destroyed by other means; but when added, even in very small quantities, to the air, carbon monoxide ensures the death of the rats even when concealed in their holes. One danger attends the use of this gas, namely, that it cannot be detected by smell, and, therefore, any person accidentally entering a vessel undergoing this fumigation may meet with a fatal accident.

(*b*) *Ozone*.

Ozone, which is formed whenever electrical discharges take place and has a penetrating smell, is a powerful oxidizing agent. In presence of organic matter it readily parts with one atom of oxygen, out of the three atoms of which its molecule is composed, and in so doing produces deodorization and disinfection. It is only since electric currents of very high tension could be generated by means of transformers that the preparation of ozone on a large scale has become practicable, this gas being produced by the non-luminous discharges of these currents. Concentrated mixtures of ozone and air form very energetic bactericides, but they also destroy organic materials in a manner analogous to the action of chlorine. When the proportion of ozone in the mixture is low, no bactericidal effect is produced, but the air is deodorized in a noticeable degree; and on this account, small quantities of ozone are now generated in small high-tension electrical apparatus in crowded rooms, theatres, concert halls, and the like, in order to freshen the atmosphere. Larger quantities of ozone are employed for sterilizing water

for municipal purposes, the town water-supply of Paderborn, for instance, being sterilized by this means. The method adopted is the following: The water is allowed to trickle down in thin streams through a tower filled with coke, and in descending meets a strong upward current of highly ozonized air. In consequence of the largely increased surface presented by the water under these conditions, the ozone is enabled to penetrate, and destroys all the bacteria present, being itself reduced to ordinary oxygen in the process. The water must, of course, be freed beforehand from the coarser impurities by a rapid process of filtration.

(c) *Formaldehyde.*

Formaldehyde is undoubtedly the most important of all gaseous disinfectants. At the ordinary temperature this gas—which has a penetrating smell—is unstable in the pure state, three molecules condensing to one (polymerization) and forming a white powdery substance, "paraform," which is placed on the market, in a compressed condition, as "formalin pastilles". From this polymerized form the gas can be generated again by heating at 150° C., but on a slight fall in the temperature, polymerization sets in once more. This explains the extremely low disinfecting power of the dry vapours when disseminated in the air, the solid body immediately formed being inert. On this account the old Schering lamp, which produced dry vaporization of the formalin pastilles, was soon found to be useless: and it was only when the vapours of formaldehyde and water were generated side by side (in the Schering "Æsculap" lamp) or together that any extensive disinfecting action could be obtained. For this purpose use was made of the previously men-

tioned 40 per cent solution of the gas, "formalin," which is cheaper, commercially, than the solid paraform. The action obtained in this way, however, cannot be regarded as due to the gaseous condition, though, as the vapours undergo distribution in a manner analogous to gases, it is usual to class formalin vapour along with gaseous disinfectants. As a matter of fact, the formalin gas and water vapour are disengaged simultaneously, the gas dissolving at once in the vapour and forming minute drops of formaldehyde solution, the vapour having condensed to the form of mist owing to the fall in temperature on dissemination in the air. At the outset the warm mist, being specifically lighter than the surrounding air, rises to the ceiling, where it cools and descends again depositing on all objects with which it comes in contact a thin film of liquid formalin which destroys the bacteria. It follows, therefore, that uniform distribution of the formalin vapour in a room is not obtained unconditionally; and also that the formalin can only act in places where the vapours are able to undergo deposition. In any event, uniform distribution depends on the action of forces by which the mixing of air and vapour is produced by motion. This mixing always takes time, and in no case is the operation or movement shared by the air contained in the pores of the articles under treatment, such air remaining stationary in the pores and unmixed with formalin, even when the general air movement is very active. On this account, formalin vapours cannot disinfect by penetration. Moreover, successful disinfection with formalin requires some time to accomplish. For instance in the case of warm objects, such as a lighted stove, the formalin deposit re-vaporizes almost at once even if formed at all, and consequently the

bactericidal action is a negative one in such places—always provided that the bacteria are not destroyed by the heat. On the other hand, if the operation be carried out properly, all micro-organisms floating about in the air, on particles of dust or drops of liquid, are destroyed, since all the true vapour issuing from the apparatus needs, to be able to condense, is to encounter surfaces cooler than itself; and it utilizes the first opportunity of condensing that is presented, namely the particles floating in the air. Each of these particles is thereby surrounded by a minute drop of water; and any other floating particles still remaining in the air will finally be caught by the mist which soon fills the room.

I. Disinfecting Rooms with Formalin Apparatus.

These briefly recorded results of scientific observation form the basis of a process now largely employed for the disinfection of rooms, the principle of which process has been adopted in many special forms of apparatus and modified methods. They all have in common the discharge of formalin and water vapour into the air of the room, but differ in respect of the apparatus for generating the vapours. Since the effect depends on the aforesaid circumstances, it is not the same in all methods. The following are well-known forms of apparatus: Czarplewsky's "Colonia," Proskauer's "Berolina," Flügge's "Breslau," and the Lingner apparatus (Figs. 10 to 13). In the first of these, water is evaporated and the steam blows out of a narrow orifice over a nozzle from which the formalin issues, and mixes with the water, the action resembling that of a spraying device (Fig. 10). In the Proskauer apparatus (Fig. 11) and also that of

Lingner (Fig. 13), steam is blown through pre-heated formalin and this becomes impregnated with formalde-

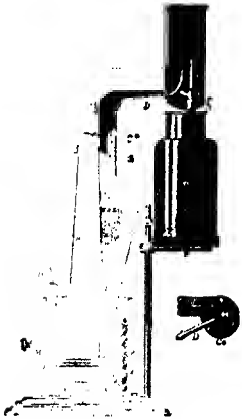

FIG. 10.—"Colonia" Formalin Sprayer.

K, Water pan. C, Lower end of steam pipe. D, Steam pipe. H, Gr, Co, Casing. L, Burner. T, Platform for the formalin bottle. G, Aspirator pipe for the formalin. S, Position of spray. The force of the steam issuing from the end of the horizontal pipe D draws the formalin out of the vertical pipe and carries it away.

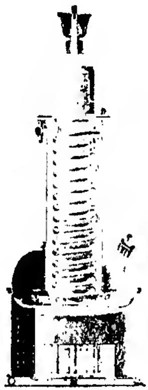

FIG. 11.—"Berolina" Formalin Apparatus.

A, Water pan. C, Formalin receptacle. D, Tubes conveying the steam into the formalin receptacle. C, Coiled steam pipe for heating the formalin. S, Section through coil. T, Feed opening.

hyde gas. The simplest apparatus is that of Flügge (Fig. 12) in which a solution of formaldehyde (about 8 per cent strength) is vaporized in a wide pan; it

being found that the vapour from this solution also contains about 8 per cent of formaldehyde.

In the case of weaker or stronger solutions the concentration either diminishes or increases continuously, so that the no longer soluble formaldehyde separates out in the insoluble, and therefore inactive, condition of paraform, in the one case from the vapours issuing

FIG. 12.—"Breslau" Formalin Apparatus.
A, Casing. B, Formalin pan. C, Burner. D, Discharge pipe.

FIG. 13.—Lingner Apparatus.
A, Casing. B, Heating burner. C, Annular water pan. D, Formalin pan. *a*, Steam pipe, *b*, *b*, Discharge pipes. P, Stand.

from the apparatus, and in the other case from the original solution. Each apparatus must be operated in accordance with the instructions provided, which also state the amount of spirit to be used for heating. The vapours issue from one or more orifices—four in the Lingner apparatus (Fig. 13)—for about an hour. The ascent and subsequent descent of the formalin mist, coupled with the continuous discharge of powerful

currents of vapour, impart to the air of the room the movement necessary for the mixing process, and thus generally ensure an efficient disinfection, which is even able to destroy spores of low resisting power, though the effect is merely superficial. Hence articles that are infested internally, such as bed linen in particular, require different treatment—steaming or boiling; and all other infected articles must be arranged so as to offer an extensive surface for the deposition of the condensing formalin. Thus pockets must be pulled out, cupboard doors and drawers opened wide, clothes spread out, and so forth.

It is found that in general, about ¼ oz. of formaldehyde and 1 oz. of water must be vaporized per cubic yard of room space in order to ensure the requisite supersaturation of the air with a sufficiently concentrated solution of formalin to afford certainty of adequate disinfection, and that the operation must be continued for at least three and a half hours. During this period the slight film of formaldehyde deposited on all the surfaces under treatment must remain undisturbed, this being the only way to ensure success. The removal of any large proportion of the active vapour by ventilation would cause premature evaporation of the deposited formalin. The mere diffusion of air through the brickwork of the walls, etc., is too slight to produce more than an inappreciable loss of formalin vapour during the continuance of the operation; but badly fitting windows and doors, or the presence of cracks or holes would lead to such an abundant interchange of gas with the external air as to allow a large proportion of the formalin mist to escape, whilst at the same time the deposited film would quickly evaporate again in consequence of the

rapid drying of the air of the room. The instructions therefore usually specify that all doors, windows and cracks, must be carefully sealed up beforehand by means of damp cotton wool or strips of paper.

One very important item, however, is omitted from most of these instructions for use. The action of formalin depends on the temperature to a greater extent than most other chemical disinfectants. Now, the quantity of formalin needed to produce effectual disinfection is calculated on the basis of a mean room temperature of 59° to 68° F.; but if, as is often done, the room to be disinfected is well aired for several days before the operation, and if the latter be performed in cold weather without the room having been warmed, the whole effect may be nullified in consequence of the low temperature. It must be borne in mind that the disinfective action gradually diminishes below 59° F. and ceases almost entirely below 46° F.

In skilled hands disinfection with formalin yields perfectly satisfactory results, and has proved especially useful as a final process of disinfecting sick rooms. At first its introduction was impeded by a difficulty which, however, was soon overcome, namely that the penetrating smell of the formalin remained in the walls and other articles so persistently as to make the room uninhabitable for several weeks. A remedy for this drawback was soon discovered, however, in the use of ammonia.

When disinfection is complete, ammonia vapour is introduced into the room, preferably by blowing it in through the keyhole by the aid of a long tube (Fig. 14). This vapour deposits on all surfaces inside the room and combines with the formaldehyde to form the inodorous compound hexamethylenetetramine. This result can be achieved completely with about 45 grains

of ammonia per cubic yard of room space; and the superfluous ammonia vapour is dissipated in a few hours.

Special mention should be made of the fact that no injury is caused to any articles, colours or varnishes, by either the formalin vapour or the ammonia.

FIG. 14.—Flügge's Ammonia Vaporizer.
B, Ammonia pan. L, Burner. T, Casing. R, Discharge pipe. S, Feed opening for ammonia. D, Vapour pipe. V, Sleeve for catching condensed liquid.

The following approximate quantities needed for disinfecting rooms relate to the Flügge apparatus as being the one most largely used:—

CHARGE FOR "BRESLAU" APPARATUS (TO GENERATE ½ OZ. OF FORMALDEHYDE PER CUBIC YARD OF ROOM SPACE).

Cubical content of room. cub. yds.	Formalin (40 per cent). oz.	Water. oz.	Spirit (86 per cent). oz.
10	12½	20	3½
20	17	25	8
30	20	30	10
40	26½	40	12½
50	30	45	17
60	35	50	20
70	37	55	21½
80	42	65	25
90	46½	70	30
100	50	75	31½
110	53	80	35
120	60	90	38
130	62	95	40
140	67	100	43
150	70	105	46½

The ammonia vaporizer should be charged with :—

Cubical capacity of room. cub. yds.	Ammonia (25 per cent). oz.	Spirit (86 per cent). oz.
10	5	½
20	10	1
30	12½	1¼
40	18	2
50	20	2
60	25	2½
70	30	3
80	35	3½
90	38	4
100	40	4¼
110	45	4½
120	50	5
130	53	5¼
140	58	5¾
150	60	6

2. Disinfecting Rooms without Apparatus.

(a) *The Authan Method.*

The difficulty of transporting disinfection apparatus and the liquids for use with same, especially in campaigns and manœuvres, coupled with the cost of formalin apparatus for occasional use, and finally with the high fire risk incurred by using spirits for heating, has led to the problem of vaporizing formalin being solved by means of chemical agencies. The first method of this kind was the Anthan method, introduced by Eischengrün. Authan (F. Bayer & Co., Elberfeld)—a mixture of paraform (29 per cent) and metallic peroxide (71 per cent)—is suffused with a specified quantity of water and stirred, whereupon an energetic chemical reaction is set up. The mixture effervesces and boils

after a short time, a dense cloud of steam and formaldehyde being given off. With the original preparation the reaction was complete in one to two minutes but the result was very imperfect. In the improved form the two ingredients, the amount of which has been increased by 50 per cent per unit of room space, are packed in separate receptacles, so as to prevent gradual decomposition through the absorption of moisture during storage. Moreover bicarbonate of soda has been added to the ingredients in order to delay the commencement of the reaction and prolong the stage of ebullition. This enables the authan powder to be very carefully stirred up in the water—the operator can safely leave the room as soon as the mixture commences to effervesce—and, in consequence of the more protracted liberation of vapour, a more effectual mixing with the air of the room is attained. This method, however, differs from those in which apparatus is used by the fact that the amounts of formaldehyde and water vaporized are smaller and that the liberation of the vapours continues for only a relatively short time. Consequently the vapours are distributed less uniformly, with the result that the upper parts of the room are more effectually disinfected than the lower levels, whilst one or more of the corners may escape altogether. To prevent loss of the heat disengaged by the reaction and playing an important part in the success of the method, wooden pails or pans should be used for mixing the ingredients, metals conducting the heat away too quickly.

The improved method at any rate succeeds in destroying most of the pathogenic germs present, and is therefore capable of doing good service when no apparatus is available. The cost of the method has now

been reduced to a fraction over 1d. per cubic yard of room space, so that it is but little more expensive than with the Flügge apparatus, whilst the prime cost of the latter is saved. Authan is sold in tins—bearing printed instructions—sufficient for rooms of various sizes, six, eight, ten, etc. cubic yards. The tins are provided with two gauge marks, so that when emptied they can be used for measuring the water for the authan and ammonia reactions respectively. For this latter reaction a mixture of ammonium chloride and calcium oxide is supplied with each tin, which mixture when suffused with water effervesces with liberation of ammonia and steam.

(b) *Potassium Permanganate Method.*

An efficient method based on the same principle, is the potassium permanganate method invented by Evans and Russell, and elaborated by Dörr and Raubitschek. According to this method crystalline potassium permanganate (the powdered form is useless) is suffused with a certain quantity of formalin which sets up a reaction similar to that of the Authan method.

This reaction, which consists in oxidizing a portion of the formaldehyde to formic acid, with considerable generation of heat which vaporizes the formaldehyde and water, depends for its intensity on the relative proportions of the reagents (permanganate and formaldehyde) and the water. According to Dörr and Raubitschek the most suitable ratio per cubic yard of room space is, permanganates $\frac{3}{4}$ oz.; 40 per cent formalin, $\frac{3}{8}$ pint; water $\frac{3}{8}$ pint; but Lockemann and Croner state that better results are obtained with, permanganate $\frac{7}{8}$ oz.; formalin $\frac{1}{4}$ pint; water $\frac{1}{4}$ pint. This latter recipe gives a mean vaporization of $\frac{1}{8}$ oz. of formalde-

hyde and $\frac{2}{3}$ oz. of water per cubic yard of room space, which experience has found to be ample for disinfection. The reaction is more thorough than in the case of authan, about 56 per cent of the formaldehyde used being vaporized in comparison with only 13·7 per cent of that in authan. As the result of this, the practical trials made in disinfecting a variety of articles have demonstrated the superiority of the permanganate method in thoroughness and reliability. Moreover, the comparative cheapness of the ingredients and the fact that the method is not patented are both points in its favour.

On the other hand the necessity for conveying the liquid formalin in bottles is a drawback for military purposes. This has been remedied by the use of solid polymerized formaldehyde, which, though it will not react in presence of permanganate and water alone, can be made to do so by various additions, notably alkali. Consequently, the necessary ingredients: permanganate, paraform and adjunct, can be packed in small compass in the dry state, and only need to be mixed in the prescribed proportions and suffused with water, to effect disinfection indoors. In this case also, success depends on the proper mixing of the ingredients and the water. Careful investigations by Lockemann and Croner have led them to recommend the following method: A mixture is prepared consisting of about $\frac{1}{3}$ oz. of paraform, $\frac{5}{8}$ oz. of permanganate crystals, $\frac{3}{4}$ grain of bicarbonate of soda per cubic yard of room space, and on to this is poured about 1 oz. of water per unit of space. These must be stirred up carefully with a wooden paddle about four inches wide for about half a minute; and in about three-quarters of a minute from the start the mixture will begin to froth up gradually.

The time required for disinfection is four hours. According to this recipe at least 36 per cent of the crude paraform and 46 per cent of the water are vaporized. The quantities are rather smaller than in the formalin-permanganate method; but are reported to have furnished satisfactory results in practice. The subsequent application of ammonia is carried out by any of the known methods.

It was at first thought unnecessary to take any special precaution for making the room air-tight in working without apparatus, the idea being that the rapid liberation of the total quantity of vapour precluded any loss of active material through ventilation. Since, however, the efficiency of the disinfection depends to a large extent on the length of the action of the deposited formalin on the surfaces treated, and the deposit is liable to be prematurely re-evaporated by an abundant ventilation, the practice of making the room air-tight, in the manner described above, is now generally adopted.

3. Japanese Method.

An endeavour to improve the action of formaldehyde, especially in respect of penetrative disinfection, was made by the Japanese military authorities during the campaign in Manchuria; and this attempt led to the introduction of a method which was largely used during the war and proved successful within the scope of its limitations. As history teaches, the conditions prevailing in war are such as always predispose to the spreading of serious diseases, and necessitate a system of disinfection that can be practised, without any special difficulty, in all sorts of places, and does not take up very much time. In the Japanese method,

readily portable appliances are used consisting of a wooden disinfecting shed, a boiler constructed to stand a steam pressure of six atmospheres, and a formalin receptacle. The articles regarded as likely to spread infection: uniforms, equipment, body linen, bed linen, boots, gloves, etc., are hung or piled up loosely in the air-tight chamber, into which steam is blown, under high pressure and mixed with formalin, through a spraying device mounted in the upper part of the front wall. This device disperses the current of steam and directs it against the rear wall, from which it is thrown back on all sides. A portion of the air of the chamber is expelled through an aperture at the bottom, the remainder of the air becoming intimately mixed with the vapour owing to the suitable arrangement of the spraying device. At first sight the method appears very similar to the ordinary system of room disinfection; but really differs therefrom considerably inasmuch as so much formalin vapour is admitted to the chamber that the temperature of the air and vapour mixture rises to as high as 140° F., whereupon the steam is shut off.

The formalin-vapour mist produced in this way acts much more energetically than in the ordinary method of room disinfection, so that the duration of the operation can be shortened to one or two hours without impairing the results; in fact, it is sometimes abbreviated to half an hour. In the latter case, steam is admitted to raise the temperature of the chamber to 140° F., and a large quantity of formalin is then sprayed in during one minute. It has been calculated that the amount of formalin needed per cubic yard of room space is ⅜ oz. of 40 per cent formalin, equivalent to ⅕ oz. of formaldehyde. The Japanese method is

imperfect in so far as the disinfection achieved is for the most part merely superficial. The vapours flowing into the chamber are condensed at once, owing to the extensive cooling, and mix with the air of the chamber to form mist. Hence they are in no wise suitable for displacing the air in the pores of the articles treated, being obliged to condense on coming in contact with any surface. In practice the method suffers from the further drawback that the large consumption of formalin renders it extremely expensive—though the Japanese regard this defect as counterbalanced by the rapidity of the method and the low cost of the apparatus; and it is also troublesome to carry out, by reason of the escape of formalin vapour through unavoidable leaks. On the other hand, it must be admitted that the surface disinfection obtained by the method is exceedingly thorough, and that a penetrative effect is sometimes achieved in consequence of the wetting of the articles by the copious fog, whilst there is no risk of injuring them, especially leather and furs. At all events the majority of the disease germs present are killed, provided the operation is conducted with skill, and therefore the method does admirable work.

CHAPTER IV.

COMBINED SYSTEMS OF DISINFECTION.

UNDER this heading will be described, not any special systems consisting in the simultaneous or successive use of different disinfectants for the attainment of a particular purpose, but rather mutually complementary combinations of physical and chemical disinfection processes. Strictly speaking, any increase in the temperature of a disinfecting liquid forms a combination of physical and chemical disinfection, since the action of the chemical process is supplemented by the heat, and *vice versa*. Such conditions, however, need no further discussion. For the combination of steam and chemical disinfectants the biological considerations are comparatively simple, and the chief advantage of such combined methods resides on the physical side.

From the biological standpoint, the following considerations apply: Water at boiling temperature has a very powerful destructive action on spores. Steam being a gas, its use in combination with other agents is restricted to those which are either already gaseous or at least volatile, and among these, formaldehyde occupies the highest position. It is now ascertained beyond any doubt that the disinfecting power of steam at 212° F. can be further augmented by admixture with volatile disinfectants. This can easily be demonstrated in the case of highly resistant spores. In prac-

tice, however, this is of no special importance, the disinfectant properties of steam at the above temperature being already so great as to exceed the needs of most practical instances. Now the great advantage of disinfecting with steam is that, in closed apparatus, it displaces the air completely, even in the pores of the articles treated, and thus quickly achieves a maximum penetrative effect—provided the pores are not choked up—without softening the articles themselves. The reason why steam disinfection is not applicable in all cases is that the high temperature of the steam destroys many articles, especially those of leather or fur. In these circumstances the idea naturally suggests itself to combine volatile or gaseous disinfectants with water vapour generated at low temperature by the aid of a vacuum, and which under ordinary conditions has practically no disinfectant power below 176° F.

The vapour, inert *per se*, which rapidly penetrates through porous articles, will act as a carrier of a powerful disinfectant and enable the latter to act inside the articles. The experiments carried on by Rubner to ascertain how this could be done, showed the possibility of combining saturated water vapour of low temperature with a whole series of disinfectants, seemingly adapted to furnish suitable results. He found that carbolic acid, sulphur dioxide, hydrogen peroxide, and, more especially, formaldehyde, will mix in sufficient quantity with water vapour when exposed to boiling water or the vapour itself is blown through their solutions. On the other hand the percentage of disinfectant in the combined vapours differs considerably from that of the boiling liquid; and the ratio of these concentrations varies considerably, in turn, with the alteration effected in the boiling temperature by altering the

pressure of the air. To bring this state of affairs into a clear light the following table, relating only to formaldehyde, is given, showing the boiling points of the formaldehyde mixture at different pressures, and the percentage of formaldehyde in the resulting vapours:—

	760 mm. pressure.		360 mm.		260 mm.		113 mm.		100 mm.		16 mm.	
Solution. per cent.	B.P. °C.	Distillate. per cent.	B.P. °C.	Distillate. per cent.	B.P. °C.	Distillate. per cent.	B.P. °C.	Distillate. per cent.	B.P. °C.	Distillate. per cent.	B.P. °C.	Distillate. per cent.
1	99·5	1·5	88	0·77	...	—	57	0·42		...	23	0·12
2	98·5	3·0	85	1·60	70	1·10	57	0·42	51	0·72	23	0·12
4	97·9	5·5	...			...	—		—		...	...
8	96·9	10·1	78	5·30	—	...	54	2·8		...	23	2·0
12	—	12·9	—	—	—	...	—				—	...
16	96·0	15·0	75	10·5	—	—	49	5·4		...	24	4·4

This demonstrates that, at ordinary atmospheric pressure, the vapours contain more formaldehyde than the boiling liquid; but that when the pressure is artificially reduced the concentration of the vapours diminishes considerably in proportion to the liquid as this reduction proceeds. Rubner also found that the penetrative power of attenuated vapours into porous articles is not inferior to that of steam at 212° F. The biological action of saturated water vapour at low temperatures, in combination with a series of volatile disinfectants, was investigated by Christian. The results, as might be expected, showed the superiority of formaldehyde over all others as an adjunct to water vapour at 112° to 140° F. However, in order to utilize the activity of formaldehyde to the full, an approximately 8 per cent solution of that substance

must be used, at the temperatures in question, the resulting vapour containing about 3 per cent of formaldehyde. The destructive effect of this vapour on spores is equal to that of steam at 212° F.

Very favourable results were also obtained with thymol, though only at temperatures above its melting-point (178½° F.). Apparently the vaporization of thymol from the liquid proceeds far more energetically than from the crystalline substance. Remarkably enough the best results were obtained from solutions or emulsions of 2 to 5 per cent strength, which also act more powerfully than those of higher concentration. No certain explanation of this fact has yet been adduced. Among the other volatile substances, carbolic acid, carvacrol, and acrolein rank about equally but are not capable of practical application; whilst hydrogen peroxide, oil of turpentine, iodoform, naphthalene, and the other substances examined have no bactericidal properties at all under these conditions.

I. Gärtner's Method of Disinfecting Books.

The disinfectant properties of alcohol in combination with water vapour and diminished pressure have been utilized by Gärtner in devising a method which has been patented by A. Scherl, Berlin, and is adapted to the disinfection of books. The apparatus for this method is constructed by Wegelin & Hübner, Halle-on-Saale. The method is based on the principle of admitting alcohol vapour into a pre-heated vacuum chamber, the vapour condensing on the surface of all the articles therein and thus destroying any disease germs present. The apparatus consists of the disinfecting chamber, heater, and auxiliary appliances. The

books are raised to a temperature of 125° F. in the heater, which takes the form of an ordinary hot cupboard in four parts, the walls and partitions forming water jackets. The heating of the books proceeds from the outward surfaces by conduction alone, and thus it takes at least several hours to warm them through when the volumes exceed a moderate thickness. From the heater the books are transferred on four slides to the disinfecting chamber, and are arranged on end with the covers opened out. The disinfection chamber is provided with a water jacket 3¼ inches thick, which is heated to 140° F. before the books are introduced, so that this temperature prevails approximately throughout the chamber. The chamber being hermetically closed, the internal air is pumped out until the pressure gauge marks only 60 mm. of mercury, equivalent to a vacuum of 700 mm. According to Gärtner, under these conditions the leaves of the books separate and stand apart. In the meantime a disinfectant fluid, consisting of water and alcohol in equal parts (about 3 gallons per 1000 books), is heated to 176° F. in a copper vessel on the water bath, this temperature corresponding approximately to the boiling point of alcohol under ordinary pressure. The copper vessel is hermetically closed and connected with the disinfection chamber by opening the intervening tap, whereupon the disinfecting liquid boils immediately owing to the diminished pressure. The vapours thus liberated are conducted into the chamber through eight uniformly distributed perforated pipes, which, in order to prevent condensation, are mounted alongside corresponding steam pipes. At the same time the said pipes are arranged in covered trays, which collect any liquid condensing at the perforations, and thus prevent the

spurting of such liquid into the chamber. The admission of vapour is continued for fifteen to twenty minutes, by which time the vacuum has receded to 400 mm. The books in the chamber being several degrees cooler than the internal space and the alcohol vapours, the latter condense as a thin film on the surface of the books, which are thereby gradually warmed to 140° F., whereupon the alcohol vaporizes anew. At the end of one to one and a half hours, the vapour atmosphere is expelled from the chamber by the admission of air, an operation which takes ten to fifteen minutes; and after half an hour longer, to enable the final traces of disinfectant to be eliminated by evaporation in the warm air, the process is complete.

When the chamber is opened, a little over half a pint of condensed liquid (containing about 30 per cent of alcohol) will be found at the bottom. According to Gärtner all pathogenic germs, except sporulating anthrax and tetanus bacilli, are destroyed with certainty by this treatment, especially tubercle bacilli, staphylococci, and the bacilli of diphtheria, typhus, dysentery, etc.

The method is chiefly one of surface disinfection, though, by reason of the technical arrangements employed, it approaches very closely to a true penetrative process. Whilst the prearranged vacuum generates true vapours from the already boiling hot disinfecting liquid, these vapours destroy the vacuum and set up a gas pressure which induces condensation. The resulting fall in pressure does not, perhaps, play any important part in relation to the subsequently admitted vapour. Condensation naturally takes place on the cooler surfaces, i.e. on the leaves of the books; and if it be really the fact that the evacuation of the air in

the chamber causes the leaves to stand apart, then practically all portions of the books that are accessible to disease germs will be exposed to the disinfecting liquid, which—as there seems no reason to doubt—is capable, from its composition and temperature, of destroying the vegetative forms of pathogenic germs in the time allowed for the operation. A few remote hiding places, such as where the leaves are fastened, and into which the mixture of air, vapour, and mist cannot penetrate, will always escape treatment; but since by reason of their small dimensions these places will also very soon attain the temperature of 140° F., the majority of the concealed germs will probably be destroyed. On account of this last named circumstance, the method is not a perfect one; but, provided the technical arrangements, especially the isolation of the leaves and the distribution of the vapour, act properly, that circumstance is practically negligible. On the other hand, the method is very expensive, the prolonged heating up of the books and chamber (the latter taking over two hours), the heating of the disinfecting liquid in the water bath, and the heating of the steam pipes in the chamber, entailing a large consumption of fuel. The attainment of the vacuum necessitates the provision of an air pump, and the chamber must be strongly built and air tight. Finally, the disinfectant used, alcohol, is one of the dearest of all.

II. Formalin Vapour Method.

On the basis of experiment Von Esmarch, in 1902, proposed to employ water vapour, formalin, and a partial vacuum for protective disinfection. He, however, did not fully recognize the true importance of the vacuum in the production of unconfined water vapour of low

temperature, but merely operated with an initial vacuum, which soon disappeared in consequence of the liberation of steam.

(a) *Weimar Apparatus.*

Von Esmarch's ideas found application in a number of disinfection apparatus, only one of which, however, the Weimar apparatus (Gebr. Schmidt, Weimar) appears to be still on the market. In this apparatus the disinfection vessel, after being charged with the material under treatment and hermetically closed, is evacuated, by means of an air pump, to a pressure of about 160 mm. mercury gauge (equivalent to a 600 mm. vacuum), whereupon steam laden with formaldehyde is admitted through a number of distributed nozzles. The steam under slight pressure (temperature 216° to 231° F.) is charged with formaldehyde from a drop apparatus in the feed pipe (Fig. 15). In consequence of the admission of steam into the chamber the vacuum is diminished, and at the same time the temperature rises to about 158° F., at which point the supply of steam is shut off until the internal temperature has receded. The steam cock is then reopened, and again closed, so as to maintain the temperature at 158° F. for about an hour. By the time the process is completed, the vacuum has fallen to 200 mm. or thereabouts, so that the chamber contains air at a tension of 160 mm. and steam at a tension of 400 mm., that is to say, charged with about one-third of air. Moreover a large portion of the admitted steam is obliged to condense on the surfaces of the materials, and is liable to choke up the pores in same. Even assuming, from the nozzle arrangement, that the air and steam are perfectly mixed, this mixing cannot

extend to the interior of the pores. The forces capable of driving the air out of the pores are not present to more than a slight extent, and rest exclusively on the partial elimination of the original vacuum, the

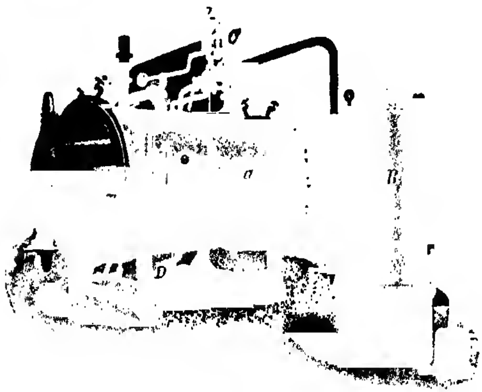

FIG. 15.—Weimar Apparatus.

a, Disinfection chamber. B, Steam boiler. C, Drop apparatus for formalin. D, Air pump.

force of gravitation which acts in ordinary steam disinfection being excluded by the whole arrangement of the method. It therefore follows that disinfection of this kind must be imperfect, especially as regards penetrative effect.

(b) *Hamburg Apparatus.*

Kister and Trautmann, who originally worked on the above lines, afterwards recognized the true import of the vacuum, namely in the production of unconfined

water vapour at low temperature, so as to bring about the same physical conditions as with ordinary steam under atmospheric pressure. However, to maintain these conditions at constant value, it is necessary to continue to evacuate the vessel during the operation of disinfection, so that, despite the liberation of the vapour, a constant pressure is obtained. The original, unimproved Hamburg apparatus (Boy & Rath, Duisburg) comprised a disinfection vessel, in the bottom of which stood a pan, charged with a 1 per cent solution of formalin and adapted to be heated, and an exhausting device operated by a steam injector. This apparatus was attended with the same defects as those first used for steam disinfection. The vapour liberated from the heated liquid after the evacuation of the air in the chamber was obliged to ascend through the air to the top of the chamber, to then expel the air from above, and consequently became so charged with air during its upward course as to imperil any regular action. In the newer form of apparatus (Fig. 16) constructed by R. Hartmann, Berlin, the vapour liberated from a 2 per cent solution of formaldehyde is admitted into the top of the disinfection vessel, and consequently the apparatus would be perfect, from the scientific point of view, were it not that the method of working exhibits certain technical defects. For example, the steam injector is not capable of continuously maintaining a sufficient vacuum to keep the vapour temperature below 149° F., which is the highest permissible temperature for the disinfection of leather. On this account the prescribed working temperatnre (158° F.) of the Hamburg apparatus renders it unsuitable for that purpose. Moreover the initial solution contains only 2 per cent of formaldehyde, which liberates a vapour

containing only 1·1 per cent of that substance and therefore not capable by a long way of exerting the maximum disinfectant power of the agent. Again,

FIG. 16.—Hamburg Apparatus.

A, Disinfection chamber. B, Formalin vessel. C, Steam boiler. D, Steam injector.

the consumption of formalin in this method is so large that the use of the most suitable formaldehyde solution (6 to 8 per cent strength) would be too expensive.[1]

[1] The Hamburg apparatus can now, if desired, be supplied with an air pump and formalin trap, and thus acquires the character of the Rubner apparatus.

(c) *Rubner Apparatus.*

The Rubner apparatus (F. & M. Lautenschläger, Berlin) consists of a disinfection chamber, reciprocating air pump, formalin generator and formalin trap; and in cases where there is no available connection with a steam main, it is also fitted with a steam boiler (Fig. 17). The apparatus is universal in its action, being capable of operating with steam under pressure and *in vacuo*, with or without combination with chemical disinfectants. The steam generator serves a variety of purposes: (1) For ordinary steam disinfection with or without pressure; (2) for heating the radiators supplying heat to the disinfection chamber before and after the operation; (3) for working the air pump; (4) for heating the formalin liquid by means of a coil. The disinfection is carried on in the following manner: After the chamber has been charged with the material under treatment and has been moderately pre-heated, all the vessels constituting the apparatus being hermetically closed, a vacuum of 600 mm. is produced throughout the apparatus by means of the air pump, and the formalin liquid is heated to boiling by the steam coil, the boiling-point under the prevailing pressure being 140° F. The vapours enter the disinfection chamber from above, and, as in the ordinary steam disinfection apparatus, expel the air by degrees from above downwards, so that this air escapes at the lowest point of the chamber, traverses the formalin trap and air pump, and is discharged through the boiler fire into the atmosphere. When the chamber is filled with formalin vapour, which is the case when the thermometer in

the escape pipe registers 140° F., the formalin vapour escaping from the chamber is condensed in the water-cooled formalin trap and retained there. The air pump and formalin generator are regulated so that, whilst maintaining the vacuum, the flow of vapour through the apparatus is reduced to a minimum. Given efficient cooling of the formalin trap none of the disinfection vapour is lost, so that the condensed liquid can be

Fig. 17.—Rubner Apparatus.

A, Steam boiler. B, Air pump. C, Formalin generator. D, Formalin trap. E, Disinfection chamber. F, Shelves for material under treatment. G, Chamber door.

used over again after being pumped into the formalin generator. This arrangement ensures, on the one hand, the advantage that the original concentration of the formalin liquid can be maintained without difficulty, thus preventing the deposition of paraform which would occur if the concentration increased as a result of boiling, since the vapour from the 8 per cent liquid contains only 3 per cent of formaldehyde. The chief advantage, however, resides in the cheapness of the operation, the

same charge of liquid sufficing for a number of disinfections.

These technical improvements fill a wide gap in practical disinfection. Whereas, formerly, leather goods and furs could only be disinfected in an imperfect manner by washing with disinfectant solutions, and never without risk of damage, these materials, which are very susceptible to the effect of heat, can now be disinfected thoroughly without the least danger of injury.

An interesting modification of the Rubner apparatus is the portable form illustrated in Fig. 18. The disinfection chamber is charged from the side, and the rearwardly mounted steam boiler is fired from the back, whilst the formalin generator, formalin trap, and air pump, are mounted under the driver's seat. Since the walls of the apparatus have to withstand considerable external pressure, they would, if constructed in the ordinary manner, have to be very heavy to ensure strength. To obviate this a special form of construction has been devised by the makers, both for the portable apparatus and a number of the stationary patterns, namely by building the walls in segment of a sphere, with the convexity partially directed inward, the edges being rounded off. In this way the pressure, which otherwise would tend to force the middle portion of the flat walls inward, is distributed uniformly over the whole surface. The barrel form of chamber which would achieve the same purpose leads to difficulties in charging the apparatus.

The new method of disinfection has also a less injurious action on other sensitive materials, fine fabrics, colours, etc. than is the case with steam at 212° F. It has also afforded the first satisfactory solution of the

difficult and much discussed problem of book disinfection. If the books be piled up loosely in a properly working vacuum apparatus, they will all be thoroughly disinfected without the slightest injury to the leaves, text, or binding. Consequently the method has the following points of superiority over the Gärtner method made public in 1909: (1) Uniform penetrative action, even the smallest air spaces being traversed by the vapour; (2) increased bactericidal properties, which extend even to the spores of anthrax and tetanus

FIG. 18.—Portable Rubner Apparatus.

A, Steam boiler. B, Chimney. C, Disinfection chamber. D, Air pump. E, Formalin generator. F. Formalin trap.

bacilli, whereas vegetative forms alone are killed by alcohol vapour; (3) the duration of treatment is reduced to one hour at most, as compared with the four to five hours of the Gärtner method; (4) cheapness, the first charge of formalin for a chamber with a cubical capacity of 3 cubic yards costing 12s. Since the same charge of formalin can be used repeatedly, the cost per operation—apart from the fuel consumed—is only 7½d.

if the charge is used twenty times, and of course less if the same charge be employed longer.

It may be expected that the labours of science and technics will yield additional fruit in connection with remedying existing small defects, and introducing further improvements. Taking all things into consideration, however, sufficiently powerful weapons are already available against all possible dangers of infection; and the successful application of these weapons resolves itself into the suitable training of experts, the education of the public, and efficient supervision.

THE END.

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